Investigating the relationships between wheat-specific rainfall characteristics, large-scale modes of climate variability and wheat yields in the Swartland region, South Africa.

by

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ABSTRACT

Wheat producers in the South Western Cape (SWC) of South Africa need to cope with biophysical and socio-economic systems exposing farmers to a multidimensional decision-making environment. The rainfed wheat production in the Swartland region is highly susceptible to the interannual variability of winter rainfall. Producers, therefore, need relevant climatic information to identify ways to improve profitability and to make sound economic decisions. Seasonal forecasting has the potential to provide wheat producers with invaluable information regarding the climatic conditions. However, due to the complex nature of the atmospheric dynamics associated with winter rainfall in South Africa, seasonal forecasting models have been found to have very little skill in predicting the variability of winter rainfall. Such a shortfall has created a gap for which this study has attempted to bridge.

This study aimed to investigate the relationship between wheat-specific rainfall characteristics, large-scale modes of climate variability and wheat yields in the Swartland region to assess whether these relationships could provide useful climatic information to the wheat farmers. Six wheat-specific rainfall characteristics (total *rainfall*; number of *wet days*; number of *'good' rainfall* events; number of *heavy rainfall* events; percentage *'good' rainfall*; and the number of *dry dekads*) on various time scales (winter; seasonal; monthly and dekadal) were correlated against wheat yield records over a 17 year period from 1994 to 2010. From this analysis, the distribution and timing of the rainfall throughout the wheat growing season (April to September) emerged as an important determinant of wheat yield. An accurate statistical wheat prediction model was created using farmer stipulated rainfall-wheat yield thresholds. Three teleconnections (El Niño-Southern Oscillation [ENSO], Antarctic Oscillation [AAO] and South Atlantic sea surface temperatures [SSTs]) represented by eight climate indices (Nino3.4 Index, Ocean Nino Index [ONI], Southern Oscillation Index [SOI], AAO index, Southern Annular Mode Index [SAM], South Atlantic Dipole Index [SADI], South Western Atlantic SST Index [SWAI] and South Central Atlantic SST Index [SCAI]), were correlated against wheat yield data over a 17 year period from 1994 to 2010. The relationships between the three teleconnections and wheat yield in the Swartland were established. Teleconnection-wheat yield correlations were found to be limited, with regards to the application of this information to farmers, due to the lack of a comprehensive understanding of the dynamics of how the three teleconnections influence the local climate and, therefore, the wheat yield in the Swartland. The eight climate indices, representing the three teleconnections, were correlated against the six wheat-specific rainfall characteristic indices from each of the three study areas over the period from 1980 to 2012. The state of

ENSO during the first half of the year was shown to be correlated with rainfall characteristics during both the first (April to July) and second (July to September) halves of the wheat growing season; however, these correlations differed in their sign. Correlations suggested a negative phase of AAO was associated with above normal rainfall throughout the year across the Swartland region. Sea surface temperatures in the central South Atlantic during March to October showed significant negative correlations with rainfall during the latter half of the wheat growing season (July to October) across the Swartland region.

This study presented evidence supporting the plausibility and validity for the use of the state of large-scale modes of variability in the prediction of wheat-specific rainfall characteristics and aggregated yields in the Swartland region. This has the potential to provide useful information to wheat farmers in the Swartland to aid in their decision making process.

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PLAGIARISM DECLARATION

I know the meaning of plagiarism and declare that all of the work in the dissertation, save for that which is properly acknowledged, is my own.

Signed: ________________________________ Date: 14 April 2014

CHAPTER 1: INTRODUCTION

The agricultural sector in South Africa is a significant contributor to the country's economy contributing 15% (considering the strong forward and backward links the agro-industrial sector has into the economy) of the gross domestic product (GDP) (Schulze *et al.* 2007) and creating ~7.5% of the country's formal employment (Schulze *et al.* 2007), whilst also influencing food-security. The highly diverse agricultural sector in the winter rainfall region of the Western Cape province of South Africa plays an important role in the economy, generating roughly 23% of the total value added by the agricultural sector in South Africa (WCDA undated).

The rapid rate of urbanization in South Africa over the past decades has seen a shift in consumer behaviour towards more ready-to-eat food types. Wheat based products (mainly in the form of bread) have become a dietary staple in the majority of South African households, making wheat an important crop to national food-security. Wheat is considered the second most important grain crop in South Africa, after maize (Meyer & Kirsten 2005). Although wheat is grown in all nine of South Africa's provinces there are three major regions producing over 80% of wheat production over the past ten years – namely, the Western Cape (37%), Free State (29%) and the Northern Cape (15%) (GrainSA 2013). The majority of wheat production in South Africa is done so under dryland conditions, roughly 80%, with the additional 20% being grown under irrigation (Department of Agriculture, Forestry and Fisheries [DAFF] 2006). The wheat grown in the winter rainfall region of South Africa is planted between mid-April and mid-June, whilst in the summer rainfall areas wheat is planted from mid-May until the end of July (DAFF 2006).

The South African agricultural sector has endured significant structural changes over the past two decades (Breitenbach & Fenyes 2000).The introduction of the Marketing of Agricultural Products Act 47 of 1996 abolished the existing market control boards, successfully transforming the stagnant state-controlled sector into a vibrant market economy (Meyer & Kirsten 2005; Baiyengunhi & Sikhosana 2012). However, the removal of state support to farmers in South Africa along with the implementation of low import tariffs, to encourage international trade, left farmers in certain sectors (including wheat) unable to compete with wheat produced by state subsidised farmers from developed countries (Breitenbach & Fenyes 2000). High-volume, low-value production of agricultural products, intended for local markets became unsustainable for many small farmers; some of which, sold their land or shifted to an alternative crop. The total number of farms in South Africa today is less than two-thirds the number operating in the early 1990s, with many farm lands being converted to other land uses or consolidated into larger farming units effectively shifting the agricultural sector to large-scale intensive farming (World Wildlife Fund [WWF] 2010). As a result of these factors, the area of arable land cultivated in South Africa for wheat production has decreased by 75% between 1988 and 2012 (DAFF 2013).

The area of wheat production in the Western Cape has not experienced as great a decline as the rest of the South Africa, particularly the Free State, and has become the single most important wheat production area in the country, with 53% of the total area cultivated for wheat in South Africa during 2012 occurring in the province. Wheat is grown in two regions within the Western Cape – namely, the Swartland and the Rûens regions. Interestingly the extent of the decline in total area planted within the wheat industry has not been mirrored within the wheat production records as productivity (yield) has risen by over 300% between 1990 and 2012 (DAFF 2013) due to the improved farming techniques and mechanisation. Despite this increased productivity, South Africa has not been able to meet the demands of the population since 1988 and has become a net importer of wheat (Baiyengunhi & Sikhosana 2012).

The majority of South Africa experiences rainfall during the summer months with the exception of a region in the southwest, which receives most of its rainfall during the winter months. The northward migration of the Intertropical Convergence Zone (ITCZ) during austral winter and the associated northward movement of the global circulation cells, results in the equatorward shift in the position of the South Atlantic High Pressure allowing temperate weather systems (extratropical/mid-latitude cyclones and cold fronts) to make landfall over the southwestern part of South Africa. The winter rainfall region, which encompasses areas of the Western and Northern Cape provinces of South Africa, is characterized by significant interannual variability. Over the past decade there have been numerous studies attempting to determine the mechanisms associated with this interannual variability (Reason *et al.* 2002; Reason & Jagadheesha 2005; Reason & Rouault 2005; Blamey & Reason 2007; Philippon *et al.* 2011). A number of teleconnections have been shown to influence the winter rainfall in the region – namely, South Atlantic sea surface temperatures (SSTs) (Reason *et al.* 2002; Reason & Jagadheesha 2005), Antarctic Oscillation (AAO) or Southern Annular Mode (SAM) (Reason *et al.* 2002; Reason & Jagadheesha 2005; Reason & Rouault 2005) and El Niño-Southern Oscillation (ENSO) (Philippon *et al.* 2011).

This study focuses solely on the Swartland region, located along the western side of the Western Cape province of South Africa (Figure 1.1, see yellow shaded area). The regions climatology is influenced by the cold Benguela upwelling system that boarders it to the west and the northern extent of the Cape Fold Mountain belts running parallel to the coast to the east. According to the Köppen climate classification system the region experiences a typical Mediterranean climate (Csa), with clearly defined cool, wet winters and warm, dry summers.

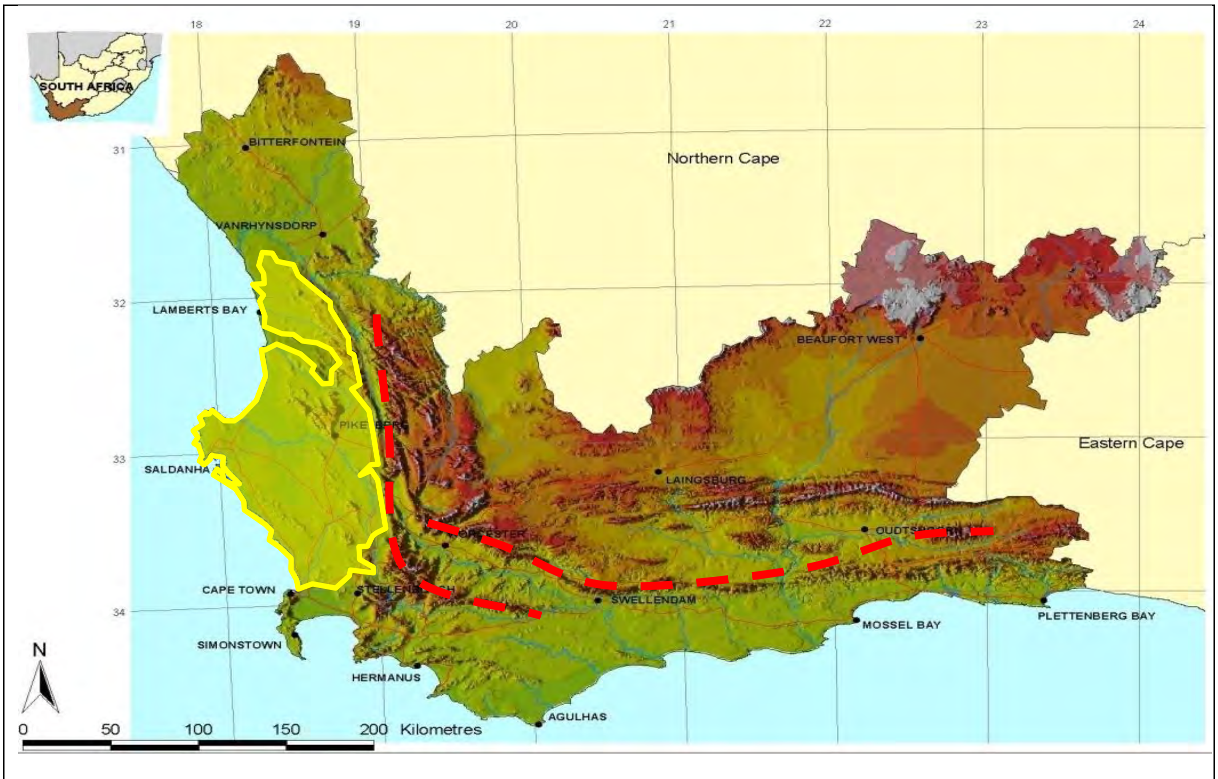

Figure 1.1: Map of the Western Cape province, South Africa. The Swartland region is indicated by the yellow shaded area, whilst the dashed red line indicates the Cape Fold Mountains. ***Source:*** *Department of Environmental Affairs and Tourism (DEAT) 2001*.

The study region was defined as the area to experience a typical Mediterranean climate and in which wheat farming occurs. The Swartland receives roughly 80% of its annual rainfall between April and September. This clear seasonality, unlike the Rûens region to the east, centres this study's focus on the major large-scale ocean-atmospheric dynamics that influence winter rainfall in South Africa; therefore, omitting the atmospheric dynamics of summer rainfall. The winter rainfall, mild temperatures and low humidity that are experienced in the Swartland makes it suitable for growing wheat. The wheat crop is planted between April and early June and is harvested from late October through to early December. Wheat production in the Swartland region is heavily dependent on the winter rainfall as wheat is not irrigated and, therefore, highly susceptible to any irregular deviations in the winter rainfall. The rainfall greatly affects the yield and quality of wheat production, making the crop especially vulnerable to abnormally drier years.

The interannual variability in combination with the deregulating of production and market systems in the agricultural sector in the 1990s has led to a significant decrease in the economic viability of the wheat production in the Western Cape (Smit *et al.* 2010). Wheat farmers in the Swartland region have had to adapt to the changing environment by shifting from high input cost farming (wheat monocropping) to more sustainable farm management systems, such as crop rotation and mixed farming (Hardy 1998). The profit margins of wheat producers are constantly under pressure and enhanced by the need to cope with biophysical and socio-economic systems exposing farmers to a more multidimensional, hazardous and less controllable decision-making environment (Hardy *et al.* 2011; Hoffmann & Kleynhans 2011). Producers, therefore, need relevant information to identify ways to improve profitability, and numerous studies, worldwide, have investigated how farmers may use weather and climate information tools to better manage agricultural activities (McCrea *et al*. 2005; PytlikZillig *et al*. 2010). Seasonal forecasting has the potential to provide wheat producers in the Swartland region with invaluable information regarding the climatic conditions of the coming season, enabling them to make sound economic decisions (Johnston 2011). Regrettably, due to the complex nature of the atmospheric dynamics associated with winter rainfall in South Africa, seasonal forecasting models have been found to have very little skill in predicting the variability of winter rainfall (Johnston 2011). Such a shortfall has created a gap for which this study is attempting to bridge.

1.1 Aim and objectives

This thesis aims to investigate the relationship between wheat-specific rainfall characteristics, large-scale modes of climate variability (including SSTs) and wheat yields in the Swartland region. The specific objectives designed to achieve this aim, and which define the core topics investigated within this thesis are:

1. To elucidate the relationship between wheat-specific rainfall characteristics and wheat yields in the Swartland region. This objective will identify and determine the influence various rainfall characteristics have on the wheat yields.

2. To assess the relationships between global teleconnections that may influence climate variability in the Swartland and wheat yields. This was designed to establish whether the state of the large-scale atmospheric dynamics could be used as a predictor for wheat yields.

3. To evaluate any apparent influence large-scale modes of climate variability have on wheat-specific rainfall characteristics. This objective will determine whether climate indices could potentially be used to predict rainfall characteristics in the Swartland.

There have been few attempts to use rainfall based predictors in anything other than drought or flood forecasts. It is hoped that insights gained through the accomplishment of these objectives could reveal climate information that wheat farmers would find relevant and useful, enabling them to make informed decisions. The study will assess the plausibility of developing a tailored statistical forecast model utilizing the state of global teleconnections.

1.2 Thesis outline

Following this introduction is a review of relevant literature (Chapter 2) and a description of the data and experimental procedures used to accomplish the objectives of this thesis (Chapter 3). In Chapter 4, the results will be illustrated and presented before being discussed in Chapter 5. The thesis is concluded and recommendations for future work are stipulated (Chapter 5). Finally all sources referenced to within the thesis are listed, followed by the appendices.

CHAPTER 2: LITERATURE REVIEW

2.1 Wheat production in South Africa

Wheat is not indigenous to South Africa and was brought by Dutch colonists who were sent to the Cape by the Dutch East India Company in 1952. The expedition, led by Jan van Riebeeck, was to establish a refreshment station to supply fresh water and food to ships en route to the Indies. The first wheat crop was sown on the 3rd of July 1652 by the master gardener, Hendrik Boom, in the Company's garden and harvested on the 13th of January 1653 (Du Plessis 1933). The crop proved to be unsuccessful with the crop yielding only a quarter of the normal yield (Richter 2010). In 1657 production moved to the eastern side of Table Mountain, along the Liesbeeck River, which was more sheltered from the wind (Richter 2010). As demand for wheat grew, farmers migrated northwards and eastwards out of Cape Town into the Swartland and Rûens regions respectively (Richter 2010). Wheat production progressively grew in an attempt to meet the demand of an ever increasing population.

Historically countries were colonised for the purpose of supplying primary products to the empire states. Primary industries (such as agriculture and mining), therefore, became the foundation of their early economies. South Africa is an example of one such colonial country and although the economy has diversified significantly, a healthy agricultural sector remains beneficial as it contributes to the country's gross domestic product (GDP), food security, job creation, social welfare and ecotourism. Wheat is regarded as the most important grain crop in South Africa, after maize (Meyer & Kirsten 2005), contributing approximately 3% to the gross value of agriculture produced during 2004/2005 (Department of Agriculture, Forestry and Fisheries [DAFF] 2006). Wheat is mainly used for human consumption (bread, biscuits, breakfast cereals, rusks) with small quantities, often of poor quality, being marketed off as feed for livestock (Breitenbach & Fenyes 2000; Meyer & Kirsten 2005).

As is the norm in developing countries South Africa has experienced a rapid rate of urbanization over the past decades. Urbanisation causes consumer behaviours to change, as diets shift to more ready-to-eat foods. This has seen products such as bread replace foods such as maize-meal as the staple food in a large proportion of South African households (Baiyengunhi & Sikhosana 2012). Most of the wheat produced in South Africa is bread wheat, with small quantities of durum wheat, for the production of pasta, being grown in certain areas (DAFF 2006). The importance of wheat in South Africa is underlined by the inclusion of two ears of wheat in the national Coat of Arms. The ears of wheat, an emblem of fertility, symbolize; the idea of germination, growth and the feasible development of any potential; the nourishment of the people; and the agricultural aspects of the Earth (Department of Government Communication and Information System [GCIS] 2005).

The South African wheat sector has experienced significant structural changes over the recent decades (Breitenbach & Fenyes 2000). These changes include the closing of agricultural marketing boards, the phasing out of certain import and export controls and the introduction of various import tariffs (World Wildlife Fund [WWF] 2010). The Agricultural Marketing Act 59 of 1968 was introduced to regulate the marketing environment of wheat in South Africa through the Wheat Board (Smit *et al.* 2010). The Wheat Board was the sole buyer and seller of the country's wheat crop, using farming cooperatives as agents to receive, store and dispense crop (Smit *et al.* 2010). With recommendations from the Wheat Board, government would set the price of grain, flour and bread. All wheat cultivars made available for commercial production required approval from the Advisory Winter Cereal Grading Committee and were considered to be of equal quality worth (Smit *et al.* 2010). This single channel marketing system was amended in the late 1980s and early 1990s before the introduction of the Marketing of Agricultural Products Act 47 of 1996 following the in-depth investigation by the Kassier Commission into the agricultural marketing in South Africa (Vink *et al.* 1998; Breitenbach & Fenyes 2000; Smit *et al.* 2010). The Act authorised the establishment and enforcement of regulatory measures to intervene in the marketing of agricultural products, which effectively deregulated the South African wheat market from a single channel marketing system to a vibrant market economy in which supply and demand would determine price (Vink *et al.* 1998; Breitenbach & Fenyes 2000; Meyer & Kirsten 2005; Smit *et al.* 2010; Baiyengunhi & Sikhosana 2012). The transformation, however, did have a few negative drawbacks. The removal of state support for farmers, along with the implementation of low import tariffs to encourage international trade, left wheat farmers unable to compete with state subsidised produces from developed countries (Vink *et al.* 1998; Breitenbach & Fenyes 2000). This triggered a shift from low-value, high volume products, like wheat, intended for the domestic markets to high-value products intended for the international market, such as deciduous fruit, citrus and game (Breitenbach & Fenyes 2000; WWF 2010). In addition to the market deregulation, land reform policies in the form of land re-distribution, land restitution and tenure reform have concerned farmers (Baiyengunhi & Sikhosana 2012). Despite the slow progress in the land reform programme, with only 2% of commercial farm lands being transferred, the uncertainty it has caused among farmers has disincentivized any further investments into farms, such as new equipment, which would improve productivity (Baiyengunhi & Sikhosana 2012). With declining farming profitability many smaller farmers opted to sell their farms. The number of farms in South Africa is less than two-thirds the number operating in the early 1990s and in many cases these lost farms have been converted to other land uses, or consolidated into larger farming units effectively shifting the agricultural sector to large-scale intensive farming (WWF 2010).

Prior to these factors coming into effect South Africa produced, on average, 1,656 million tons of wheat from 1.969 million hectares of land over the five year period between 1970 and 1974 (all statistics within this paragraph have been derived from DAFF 2013). Thirty three years later, the average amount of land planted for wheat over the previous five years (2008-2012) has progressively declined (from 1988, Figure 2.1) by a massive 69% to 0.613 million hectares. However, this decrease in cultivated land has not been reciprocated in the wheat production record. In fact the amount of wheat produced has increased from the early 1970s to an average of 1,898 million tons of wheat (2008-2012). This equates to a more than 360% increase in the productivity of the land from the early 1970's to present. The average yearly consumption of wheat in South Africa during the early 1970's was a mere 1.39 million tons and has risen by 220% to 3,112 million tons (2008-2012). During the 1970s and 1980s the South African wheat sector was able to produce enough wheat to meet the demand of the population. However, with the relatively constant production of wheat the demand, caused by a high population growth rate, surpassed domestic supply in 1989. Unavoidably, importations of wheat were required to meet the countries needs and South Africa has remained a net importer of wheat since (Baiyengunhi & Sikhosana 2012).

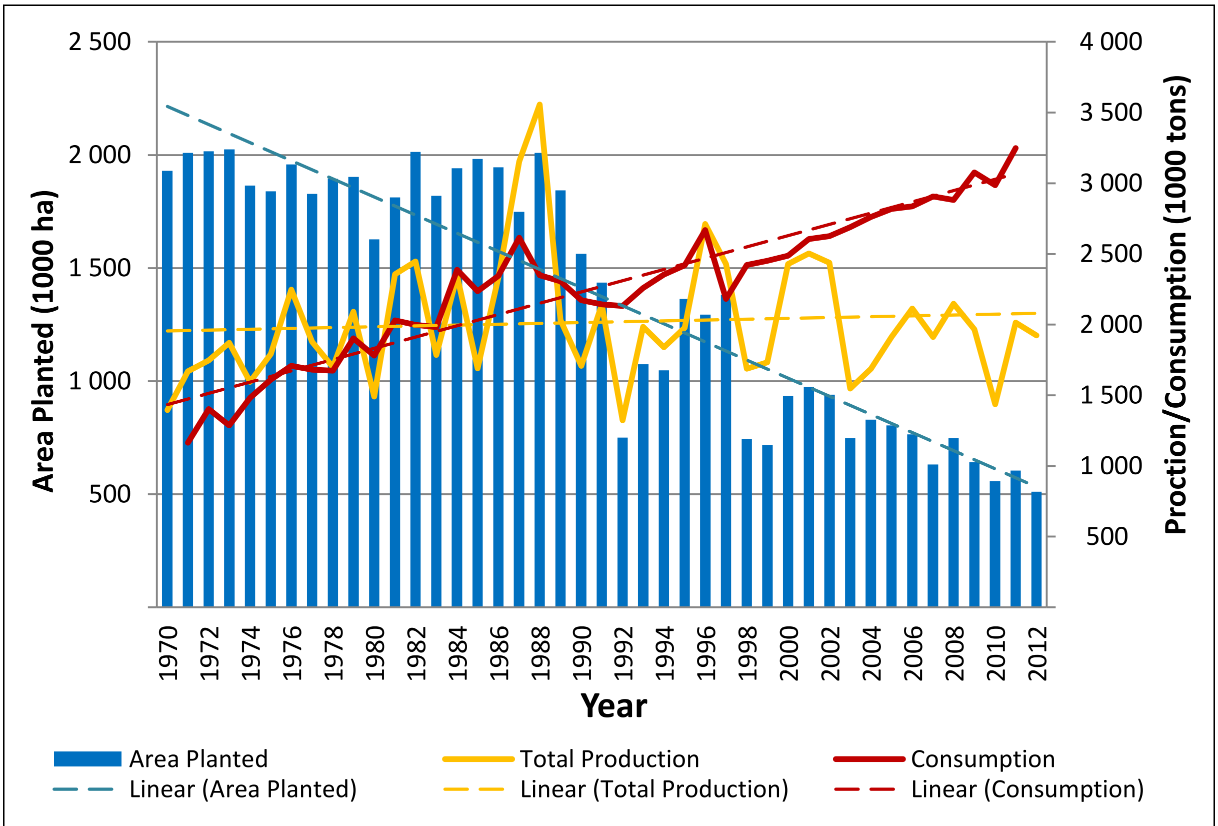

Figure 2.1: Wheat trends in South Africa between 1970 and 2012. Blue bars indicate the total area cultivated for wheat, with the blue dashed line indicating the linear trend over the period. Solid yellow (red) line indicates total amount of wheat produced (consumed) with the yellow (red) dashed line indicating the corresponding linear trend over the period. *Data from Department of Agriculture, Forestry and Fisheries (DAFF) 2013.*

Wheat is grown in all nine of South Africa's provinces with the three major contributors to production over the past ten years being the Western Cape (37%), Free State (29%) and the Northern Cape (15%) provinces (GrainSA 2013). Wheat production in South Africa is unique as there are three distinct wheat producing regions. In the Free State province winter wheat is grown under dryland (rainfed) conditions, relying on stored soil moisture from the preceding summer and autumn months to sustain the wheat crop through the drier winter period (Smit *et al.* 2010). The winter wheat is sown from mid-May until the end of July (DAFF 2006). Dryland spring wheat (differs from winter wheat in that it has lower cold requirements (vernalisation), a shorter growing period and produces fewer tillers) is sown in the Mediterranean type climate of the Western Cape province with planting occurring between mid-April and mid-June. Roughly 80% of the total area cultivated for wheat in South Africa is under dryland conditions (DAFF 2006), with the additional 20% being grown under irrigation (the third region) adjacent to major rivers (Van Niekerk 2001).

Triticum aestivum, commonly known as bread wheat, is a C3 plant and is adapted to thrive in cool environments (Acevedo *et al.* 2002). The wheat plant's phenological development is divided into ten major growth stages. Each stage and phenological process is governed by different environmental requirements. Environmental factors are capable of inducing abiotic stresses in wheat, which have a negative effect on both the quality and quantity of wheat (Barnard *et al.* 1997). Drought causes stress during the plants life cycle; high and low temperatures cause heat and frost damage; and mineral stress cause deficiencies in wheat and preharvest sprouting, which has a detrimental effect on the quality of wheat (Smit *et al.* 2010). The impact of environmental factors has been extensively studied with literally hundreds of studies documenting the optimum and critical ranges that the different phenological stages of wheat are able to withstand. Porter & Gawith (1999) summarized the effect of temperature on the growth and development of wheat that has been documented in the literature. The sheer number of different types and cultivars of wheat developed and adapted to grow in varying conditions around the world results in hundreds of identified thresholds. Temperatures occurring outside these ranges (region and cultivar specific) have been shown to severely influence crops, significantly reducing yield (Porter & Gawith 1999). Both high and low temperatures have been shown to decrease the rate of dry matter production in the wheat plant and at extremes could cause production to stop all together (Porter & Gawith 1999). The response to water deficit, however, is different. Tanner and Sinclair (1983) observed an on-going resilient relationship between water uptake and dry matter production over a large range of water availability, due to water loss and carbon dioxide uptake sharing the same physical pathway into and out of leaves (Porter & Gawith 1999). Wheat production in Mediterranean type climates have been shown to be highly affected by rainfall and the amount of soil water stored in the soil before and during the growing season (Schillinger *et al.* 2008; Basso *et al.* 2012). The characteristic variability of rainfall in Mediterranean environments escalates the importance on the amount of soil moisture at the beginning of the growing season (Basso *et al.* 2012). The time-span of each of the phenological stages depends on the genotype, temperature, day-length and sowing date (Acevedo *et al.* 2002). The environmental conditions play a huge role in determining the quality and quantity of a particular wheat crop.

2.1.1 The Swartland region

In 1930 a government policy, the Wheat Importation Restrictions Act, was promulgated, effectively preventing the importation of wheat or flour into the country, which at the time accounted for 30% of South Africa's demand (Meadows 2003). This prompted an immediate increase of wheat production in the country in an effort to meet the local demand. The Swartland region, for example, experienced a 40% increase in the total area planted between 1930 and 1934 (Talbot 1947). This increased wheat farming had significant environmental impacts. In the early 1940s the Swartland region was experiencing such severe soil erosion that it was believed to be on the verge of economic collapse (Talbot 1947). Only through conscious efforts and funding from the government was the crisis in the Swartland averted and rectified (Meadows 2003). South Africa became self-sufficient in terms of wheat production from the 1960's until 1988 (DAFF 2013).

Wheat production in the Swartland region is done so under dryland conditions (rainfed); therefore, irregular deviations in the winter rainfall greatly affect the yields and quality of crop produced (López-Bellido *et al.* 1996; Acevedo *et al.* 2010; Basso *et al.* 2012), making the crop especially vulnerable to abnormally drier years. A majority of the Swartland region is deemed to have a moderate to high resource potential for wheat production (Hardy 1998). This production potential coupled with support from the government in the form of government subsidies, price fixing and drought relief, led to decades of wheat production based on monocropping and expanded into marginal areas in the Swartland (Hardy 1998). Wheat production under monocropping was only sustainable if inputs such as fertilizers, pesticides, herbicides and fungicides were increased. When the governmental policy adjustments occurred in the 1990s, deregulating production and market systems, the economic viability of wheat production in the Swartland significantly decreased (Hardy 1998; Hardy *et al.* 2011). The adjustments forced farmers to adapt their farming techniques, leading to an increase in alternative crops and cropping systems being implemented. An example of an alternative cropping system is crop rotation and is widely used across the

Swartland region. With the use of specific crops, crop rotation significantly reduces input costs as soil fertility is increased and pests, weeds and diseases are naturally controlled.

In the Swartland region, crops to have shown promise in rotation with wheat include; various legumes, from annual pasture legumes such as medics (*Medicago* spp.) and clovers (*Trifolium subterraneum* and *T. balansae*) to grain legumes such as lupins (*Lupinus alba* and *L. angustifolius*); and oilseed crops such as canola (*Brassica napus*) (Hardy 1998). Numerous crops that were suited to the Swartland conditions have been tried, such as fava beans, field peas, lentils, chickpeas, linseed and flax, but due to the lack of a stable market and processing facilities their usage has been restricted (Hardy 1998; Hardy *et al.* 2011). Despite having commercial value (in the form of canola oil and canola meal) and a moderate yield potential, canola is also an excellent break-crop in wheat production systems as it reduces diseases, weeds and pests in the subsequent wheat crop, with its extensive root system providing the additional benefit of improving soil structure (Hardy 1998; Hardy *et al.* 2011). The improved soil structure allows for better root penetration of the subsequent wheat crop and also improves infiltration rates, thereby reducing the potential for sheet erosion (Hardy *et al.* 2011). Legumes are suited for the Mediterranean type climate of the Swartland and are nitrogen-fixing plants that increase the mineral nitrogen in the soil. The legumes root structures also reduce soil density and increasing soil stability, which enhance the yield of the subsequent wheat crop (Hardy 1998).

In the marginal, drier farm lands in the northern extent of the Swartland, crop rotation alone is deemed a high risk farming strategy. For this reason many farmers employ mixed farming techniques to try to mitigate the risk of crop farming, as it provides an alternative source of income. Sheep are the most common choice of livestock used in the Swartland, as this animal is able to cope with the drier conditions and more importantly there is a stable market for lamb in South Africa. To sustain the livestock, crop-pasture rotation systems are widely practiced with hard-seeded, self-regenerating annual-pastures (medics and clovers) and perennial (lucerne) legumes being utilised (Hardy 1998). Legume pastures are often utilised in the crop rotation system in areas of lower production potential where there is a higher risk of crop failure (Hardy 1998). The legume pastures provide sheep with excellent quality fodder during winter and if managed correctly, during summer. Legume pastures also contribute to improved soil by increasing organic matter and increasing nitrogen levels in the soil profile (Hardy 1998). The pastures are an effective way of managing grass weeds without the use of herbicides (Hardy 1998).

The vast number of different strategies and crops available to a farmer has led to an increase in the complexity of crop rotation systems, thereby broadening the farm-level decision-making environment. Wheat farmers now have to cope with biophysical and socio-economic systems exposing them to a more multidimensional, hazardous, and less controllable decision-making environment (Hardy *et al.* 2011). Farmers must have a thorough understanding of the wheat plant growth and development in order to establish efficient, economic wheat management systems (Fowler 2002). To add to the complexity, a variety of different wheat cultivars exist each with their own risks and rewards. In 2010 there were 65 different dryland cultivars in South Africa, of which, 12 were specifically adapted to the Mediterranean type climate of the Western Cape region (Smit *et al.* 2010). Farmers are under pressure to choose the correct cultivar to use in the upcoming season as the decision could help to reduce risk and optimise the yields (DAFF 2010). However, this decision is not a straightforward one and is complicated by the numerous factors, which contribute to the adaptability, yield potential, agronomic characteristics and disease risks of the various cultivars (Agricultural Research Council-Small Grain Institute [ARC-SGI] 2013). A correct choice of cultivar is one that has contributed to the management of risk and achieved optimal grain yield in a given situation (DAFF 2010; ARC-SGI 2013). Therefore, it is necessary for wheat producers to know the beneficial and limiting characteristics of each available cultivar in order to make an informed decision. Considering the intricacies of soil and crop management in addition to domestic and international markets, one starts to comprehend the level of the complexity of the decisions farmers are required make. In addition, farmers are forced to cope with challenges posed by climate variability that is difficult to skilfully predict. It is, therefore, necessary to provide timeous, reliable and relevant information to farmers, which will help them to make good economical and sustainable decisions.

2.2 Climate and drivers

The interaction between the atmosphere, biosphere, cryosphere, hydrosphere and lithosphere make up the Earth's dynamic and complex climate system. To avoid ambiguity, it is important to define key terminology. Weather is defined as the momentary state of the atmosphere at a particular place with regards to variables such as temperature, precipitation, wind velocity, humidity, pressure, cloudiness and visibility (Taljaard 1994). Climate is defined as the "average weather" or as a statistical résumé of the weather variables, in terms of mean and variability, over a period of 30 years (Taljaard 1994; Intergovernmental Panel on Climate Change [IPCC] 2007). The Earth's climate system is driven by the uneven distribution of energy from the sun and its pursuit for equilibrium. Most atmospheric and oceanic circulation patterns within the climate system, from global atmospheric and oceanic circulation systems to localized sea-breezes, are an effort to distribute energy (mainly in the form of heat) from areas of surplus to areas of deficit. Due to the spherical nature of the Earth, latitudinal positioning is a major determining factor of the weather and consequently the climate experienced at a particular place. Southern Africa's positioning within the subtropics means it is dominated by the high pressure systems, which constitute the subtropical high pressure cells of the general circulation in the Southern Hemisphere. Its positioning also ensures that it is influenced by both topical, from the north, and temperate, from the south, prevailing atmospheric circulation systems (Tyson & Preston-Whyte 2000).

The Western Cape province experiences a diverse climate largely due to the varied topography. The province is influenced by the cold Benguela upwelling system on its western border and the warm Agulhas Current to the south. Rainfall is higher on the seaward side of the Cape Fold Mountains than the landward side. According to the Köppen climate classification system (see definitions in Rohli & Vega 2008), the western part of the Western Cape is considered to experience a typical Mediterranean climate (Csa) with cool, wet winters and warm, dry summers. The south eastern part of the Western Cape experiences a humid subtropical climate without a dry season (Cfa), whilst the interior Karoo experiences a cold semi-arid climate (BSk) with cold, dry winters and hot summers with occasional thunderstorms. Roughly 60%-70% of the annual rainfall occurs during the period May to September in the South Western Cape (SWC) region (Reason & Jagadheesha 2005).

Temperate disturbances in the mid-latitude westerlies are responsible for the characteristic austral winter rainfall that is experienced in the SWC. These high-frequency travelling, baroclinic Rossby waves, known as 'westerly waves', are examples of such perturbations (Tyson & Preston-Whyte 2000). Instability in the westerly wave's amplitude results in the formation of vortices, strengthening and developing into deep low pressure systems/mid-latitude cyclones. These mid-latitude cyclones develop in the Southwest Atlantic Ocean and strengthen as they move with the westerlies (Taljaard 1994; Tyson & Preston-Whyte 2000). The controlling effect of the subtropical high pressure cells over the Atlantic (South Atlantic Anticyclone) and Indian Ocean (Indian Anticyclone) greatly influence the South African climate (Tyson & Preston-Whyte 2000). During the austral summer the subtropical high pressure cells are at their most southerly positions effectively blocking and shifting the mid-latitude storm tracks south of the African continent. During winter the subtropical high pressure cells shift roughly 6° northward allowing the mid-latitude cyclones to make landfall (Tyson & Preston-Whyte 2000). The cold fronts associated with these mid-latitude cyclones are the primary source of rainfall that occurs in the SWC during winter. Other westerly disturbances, to a lesser but still significant extent, such as cut-off lows, also produce winter rainfall in the SWC region (Tyson & Preston-Whyte 2000; Reason *et al.* 2002; Singleton & Reason 2006). The intensification of the South Atlantic high pressure cell during summer causes an increase in the west-coast upwelling in the Benguela Current causing the sea-surface temperatures (SSTs) along the coast to decrease (Tyson & Preston-Whyte

2000). These cold SSTs off the west coast stabilize the air masses contributing to the summer aridity along the western side of South Africa (Meadows 2003).

2.3 Interannual rainfall variability

Winter rainfall is the SWC region of South Africa is characterized by substantial interannual variability (Reason *et al.* 2002). Over the past decade there have been numerous studies attempting to determine the mechanisms associated with this interannual variability. What follows below is a summary of this literature.

2.3.1 South Atlantic sea surface temperatures

A study done by Reason *et al.* (2002), concerned with the interannual rainfall variability of the SWC, tried to establish the potential ocean-atmosphere interaction mechanisms associated with it. Reason *et al.* (2002) used National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data to investigate circulation anomalies for anomalously wet and dry winters that occurred over the 1950–2001 period. The study presented evidence that mid-latitude South Atlantic SST anomalies, sea-ice extent in the South Atlantic sector of the Southern Ocean and the phase of the Southern Annular Mode (SAM) may influence the interannual rainfall variability in the SWC. The authors suggested anomalously wet winters were associated with the moisture flux from the subtropical South Atlantic increasing towards the SWC and a negative phase of the SAM or Antarctic Oscillation (AAO) (i.e. high pressure anomalies over the Antarctic and low pressure anomalies over the mid-latitude Southern Hemisphere, and in particular the South Atlantic sector). Additionally, the authors presented evidence that an equatorward shift of the subtropical jet over the Southeast Atlantic occurred during anomalously wet winters, resulting in a northward shift of the mid-latitude storm tracks upstream of the SWC. The western South Atlantic region, near the confluence of the Brazil and Falklands/Malvinas Currents (Reason & Jagadheesha 2005), is an important area of cyclogenesis in the Southern Hemisphere (Jones & Simmonds 1993; Tyson & Preston-Whyte 2000). Warmer SSTs in this region are favourable for an increase in the number and strength of depressions. Additionally, Reason *et al.* (2002) found warmer SSTs in the eastern South Atlantic (upstream of the SWC) and Agulhas Current retroflection zone (south of Africa) resulted in wetter winters as the warmer SSTs aided the local intensification of the mid-latitude storms near the SWC. Cool (warm) SST anomalies act dynamically like a relative increase (decrease) in orography (Gill 1982). In the Southern Hemisphere, an atmospheric layer which encounters a cool (warm) SST anomaly, 'increased (deceased) orography', will move northwards (southwards) in order to satisfy the conservation of potential vorticity (Reason *et al.* 2003). The cool SST anomalies Reason *et al.* (2002) found in the central

South Atlantic were argued to shift the mean flow equatorward. This northerly shift in the mid-latitude storm tracks would result in an increase in the number of storms making landfall in the SWC and, therefore, increase the rainfall. This warm-cool-warm SST pattern across the South Atlantic was found to be a robust feature associated with numerous anomalously wet winters observed by Reason *et al.* (2002).

Using the observed SST pattern from Reason *et al.* (2002), Reason & Jagadheesha (2005) performed idealized experiments using an atmospheric general circulation model (GCM). The study was an attempt to further the understanding of; the mechanisms potentially associated with the observed links between SWC winter rainfall and South Atlantic SSTs; and the sensitivity of the regional atmosphere to winter SST variability in this region. The study found that the models response tended to consist of an AAO type mode in the mid- to high latitudes, in addition to a modulation of the wavenumber-3 pattern over the mid-latitude Southern Hemisphere. This was consistent with Reason *et al.*'s (2002) observations of circulation anomalies associated with anomalously wet (negative phase of AAO) and dry winters (positive phase of AAO) in the SWC region. The model experiments agreed with the previous work (Reason *et al.* 2002) as changes to the latitudinal position and strength of the jet near the SWC were observed. This change in the positioning of the jet along with changes in low-level relative vorticity and moisture convergence, and latent heat flux near the SWC acted to modify the track and strength of frontal systems approaching the region and, therefore, the amount of rainfall that was received (Reason & Jagadheesha 2005). Interestingly the model's response to changes in heat flux over the South Atlantic implied a damping of the imposed SST anomalies but the near-surface wind suggested a strengthening of these conditions through the changes in Ekman transport and pumping (low-level wind anomalies cause Ekman convergence (sinking) in the upper ocean over areas showing anomalously warm SSTs and weak divergence (upwelling) over areas of anomalously cool SSTs). Reason & Jagadheesha (2005) theorised that if this occurred in reality, the opposing trend between the thermodynamic and dynamical effects could possibly account for the tendency of the observed SST anomalies to maintain their spatial distribution and magnitude for the duration of winter, resulting in the ability to influence the SWC. Reason & Jagadheesha (2005) stressed the complexity of the SWC rainfall variability and that despite their work suggesting SST anomalies in the subtropical–mid-latitude South Atlantic may play an important role in the SWC winter rainfall, other mechanisms needed to be considered.

2.3.2 Antarctic Oscillation

The Antarctic Oscillation (AAO), also referred to as the Southern Annular Mode (SAM) or high latitude mode (Reason & Rouault 2005), is the dominant teleconnection pattern of non-seasonal tropospheric circulation variability south of 20°S (Carleton 2003). The AAO is characterized by large-scale anomalies of near-surface pressure of one sign centred in the Antarctic and anomalies of the opposite sign centred near 40–50°S (Reason & Rouault 2005). These large-scale pressure differences alter the strength of the westerlies in the sub-Antarctic. A positive (negative) AAO phase is associated with anomalously lower (higher) pressures over the higher latitudes and anomalously higher (lower) pressures over the mid-latitudes. During the positive (negative) AAO phase a strengthening (weakening) of the circumpolar vortex and contraction (expansion) of the westerlies towards Antarctica (the equator) occurs (Marshall 2003).

Reason & Rouault (2005) investigated the link between the AAO and SWC winter rainfall that had been suggested in prior studies (Reason *et al.* 2002; Reason & Jagadheesha 2005). Reason & Rouault (2005) provided evidence indicating that anomalously wet winters in the SWC are associated with a negative phase of the AAO; similarly, a positive phase is associated with drier winters. The mechanisms by which the AAO influences winter rainfall in the SWC, according to Reason & Rouault (2005), involved shifts in the subtropical jet, changes in the low-level moisture flux over the region, and local uplift, low-level convergence and relative vorticity. A negative AAO phase tends to be associated with a northerly shift and a strengthening in the mid-latitude storm tracks over the South Atlantic upstream of the SWC resulting in wetter winters (conversely positive AAO phase is associated with a dry winter). The results from Reason & Rouault (2005) correspond well with the previous studies by Reason *et al.* (2002) and Reason & Jagadheesha (2005).

A variety of AAO indices exist, which differ in either the methodology (first principle component or difference in pressure between 40° and 65°S), source data (station or gridded reanalysis), climate variables (Sea level pressure, 700hPa or 850hPa geopotential height [GpH]), time scale (monthly or seasonal) or time period (Ho *et al.* 2012). No particular AAO Index has been unanimously accepted within the literature as the index of choice.

Recent studies have provided evidence, which suggest a significant association exists between the AAO and El Niño-Southern Oscillation (ENSO) during austral summer (Carvalho *et al.* 2005; L'Heureux & Thompson 2006; Ciasto & Thompson 2008; Pohl *et al.* 2010).

2.3.3 Antarctic sea ice extent

Using idealised atmospheric GCM experiments, Hudson & Hewitson (2001) found that reducing Antarctic sea-ice resulted in an increase in surface pressure and decrease in mid-latitude cyclones in the band between 30° and 50°S. With the increasing knowledge of South African winter rainfall variability (Reason *et al.* 2002; Reason & Jagadheesha 2005; Reason & Rouault 2005), Blamey & Reason (2007) further investigated the proposed relationship between the Antarctic sea-ice concentration and the winter rainfall variability. Blamey & Reason (2007) discovered a positive correlation between the rainfall and sea-ice concentration in the Weddell Sea/Drake Passage region. When the winter season was broken into early (May-July), mid (June-August) and late (July-September) seasonal periods the correlations strengthened for early and mid-winter. Looking at individual months July was shown to have the largest correlation with sea-ice concentrations. The authors found that in all cases the sea-ice pattern was present at least two months in advance of the rainfall season leading to the idea that there was a degree of predictability of the winter rainfall based on the state of the sea-ice concentration. The mechanisms, proposed by the study, which link sea-ice concentrations and sea-ice extent involve shifts in the subtropical jet and mid-latitude storm tracks with changes in low level vorticity, convergence and uplift over western South Africa and the neighbouring eastern South Atlantic Ocean. These results reinforce the mechanisms suggested by previous studies (Reason *et al.* 2002; Reason & Jagadheesha 2005; Reason & Rouault 2005). Blamey & Reason (2007) stressed the complexity of the climate variability of South Africa and the importance to not isolate a single dominant mechanism to attribute the variability too. The author's also cautioned the use of the study's results as more comprehensive investigations using ocean-atmosphere coupled models needed to be conducted in order to establish the interactions and feedback that exist between the atmosphere, oceans and sea-ice.

2.3.4 El Niño-Southern Oscillation

The impact of El Niño/La Niña-Southern Oscillation, commonly referred to as ENSO, on southern African summer rainfall is well documented and regularly investigated; however, little was known about the winter rainfall-ENSO teleconnection, with a number of studies finding no relation between the two (Reason & Rouault 2005; Blamey & Reason 2007). However, Philippon *et al.* (2011) investigated this relationship more comprehensively after Rouault *et al*. (2010) found ENSO to have an impact on the Western Cape summer climate and adjacent SSTs where the prevailing south-easterly winds drive coastal upwelling. Philippon *et al*. (2011) attributed the fact that no relationship was found prior to their study, to studies having extended winter season from May through to September in addition to having too long a study period (e.g. 1900-2000, or 1950-2000). The rainfall-ENSO teleconnection had changed due to a so-called abrupt climate shift that occurred in 1976/1977 (a shift in Southern Ocean temperature from cooler than normal to warmer than normal conditions). Philippon *et al*. (2011) found a significant association between ENSO and winter rainfall in the SWC from May to July. The impact from ENSO was found to have a strong component of decadal variability, which seemed restricted to the recent decades. Philippon *et al.* (2011) investigated the effect of ENSO on the winter rainfall characteristics finding, typically, positive anomalies in the total rainfall during the May-July period occurred during El Niño events. This wet May to June period was a result of longer wet spells, which brought more rainfall. The reverse occurs during La Niña (negative rainfall anomalies caused by shorter wet spells with less rainfall). Philippon *et al.* (2011) provided evidence supporting the hypothesis proposed by Reason *et al.* (2002) that mid-latitude storm tracks, during austral winter, shifted equatorward during El Niño events. Despite the relationship found, some rainfall events seemed independent of the ENSO life cycle, which resulted in Philippon *et al.* (2011), like previous studies, concluding that the mechanism influencing the winter rainfall in South Africa are numerous and complex.

2.4 Seasonal forecasting in South Africa

People (especially farmers) have been attempting to predict the upcoming seasonal climate for many hundreds of years. The early approaches tried to identify environmental indicators, such as the behaviour of certain plants or animals, which could be used to indicate changes in the forthcoming season's climate (Inwards 1994). The visibility of stars, for example, was used in some villages in South America to predict summer rainfall (Inwards 1994). As our understanding of our physical environment has exponentially increased over the centuries we are now able to use far more multifarious tools to make predictions about our climate. The modelling and observational studies conducted throughout the 20th century significantly developed our understanding of the Earth's climate system, so much so that the elements that affect future seasonal climate were recognised (Goddard *et al.* 2001). The concept of seasonal forecasting seems irrational when considering accurate predictions of future weather cannot be made past a few days (Hansen *et al.* 2011). However, forecasting fluctuations in the climate on a seasonal time scale is possible as they are based on a different source of predictability from that of weather forecasts (Hansen *et al.* 2011). The Earth's surface provides the predominant source of heat and moisture to the atmosphere; therefore, any changes in the Earth's surface could influence the atmosphere (Hansen *et al.* 2011). Weather forecasts must overcome the challenges of a chaotic and rapidly changing atmosphere to predict the timing and intensity of certain phenomenon, whilst seasonal forecasting is able to use the interactions between the atmosphere and the, comparatively, slowly evolving Earth's surface (Mason *et al.* 1996; Goddard *et al.* 2001; Hansen *et al.* 2011).

Seasonal predictability of the climate is only possible due to the relatively long time scales of surface boundary layer variability in comparison to the limitations of the ‘short memory’ of the atmosphere (Goddard *et al*. 2001). The upper ocean, for example, is a surface boundary layer possessing the simple property of thermal inertia, providing a degree of predictability up to a few months (Goddard *et al*. 2001). Any significant changes in SSTs from their normal conditions could disrupt weather patterns over prolonged periods (Hansen *et al.* 2011). Seasonal forecasts use these slowly evolving SSTs to predict which weather patterns are likely to occur in the intermediate future. Significant deviations of SSTs in areas of warmer waters, such as the tropics, result in stronger disturbances to the weather patterns (Hansen *et al.* 2011). In these warmer tropical waters, including the equatorial Pacific Ocean where El Niño Southern Oscillation (ENSO) events occur, SST anomalies may persist for up to six or more months (Goddard et al. 2001).

A variety of seasonal forecasting techniques exist each with their own benefits and limitations. Most seasonal forecasts involve a statistical approach and/or a dynamic modelling approach. These approaches both depend on input data, in the form of observed or modelled SSTs, historical climate data, satellite information or a combination of these (Goddard et al. 2001; Johnston *et al.* 2004). Due to the atmosphere’s inherent variability and our lack of a full understanding of the climate system it is necessary to express seasonal climatic forecasts probabilistically (Klopper *et al*. 2006, Reason *et al*. 2006). Consequently, general circulation models (GCMs) are used to provide ensembles to make probabilistic forecasts. Ensembles indicate the probability distributions of expected possible atmospheric states occurring in the forecast. Ensembles are also used to decrease the effects of errors in the initial conditions, inadequacies in the parameterizations and systematic errors in the model (Goddard *et al*. 2001, Reason *et al*. 2006). Probabilistic forecasts are never completely ‘wrong’, as they assume inherent uncertainty (Johnston 2008). Often forecasts are invariably misinterpreted by users to be ‘wrong’ when the observed outcome was simply less likely (Johnston 2008). The skill of a forecast is defined by Stanski *et al.* (1989) as ‘the accuracy of a forecast relative to the accuracy of forecasts produced by some standard procedure. Commonly used standards, which are considered to have zero skill, include; climatology, persistence and chance (guessing) (Stanski *et al.* 1989). Forecasts are often measured using a combination of factors (such as; skill, reliability, resolution, sharpness and uncertainty) to reflect the ‘accuracy’ of the forecast (Stanski *et al.* 1989).

The potential value of seasonal forecasting information to various sectors of society (specifically agriculture) was quickly grasped and became the driving force behind the development of seasonal climate forecasting (Hansen *et al.* 2011). The value of the climate information was widely recognised to exceed the cost to produce a seasonal forecast, which in itself has no intrinsic value in an economic sense (Klopper & Bartman 2003). Cane *et al.* (1994) was one of the first studies to illustrate the potential value of seasonal forecasts in Africa, when they showed that correlations between the eastern equatorial Pacific SSTs, associated with the El Niño/Southern Oscillation (ENSO), and maize yields were stronger than that of the SSTs and seasonal total rainfall in Zimbabwe. Quickly, a number of institutions across Africa began to develop their own seasonal forecasts. In October 1994 the South African long-lead forecast forum (SALFF) was founded in an effort to develop seasonal forecasting abilities in the country (Mason *et al*. 1996). This forum consisted of climate scientists from the University of Cape Town, Pretoria and the Witwatersrand along with the South African Weather Bureau (SAWB) (Mason *et al*. 1996). With more than 80% of South Africa's annual rainfall occurring between October and March (austral summer) seasonal forecasts initially issued by SALFF were only for the summer rainfall months in the early 1990's (Mason *et al.* 1996). These basic statistical models used global-scale SSTs, cloud depth and upper zonal winds as their primary predictors and quickly became inadequate as a better understanding of ocean-atmosphere dynamics developed. GCMs were recognised for becoming increasingly apt at qualitatively simulating these dynamics and so were forced with observed global SSTs (Goddard *et al*. 2001). The GCMs were able to capture the main seasonal variability of the austral summer rainfall over South Africa and so became the most suitable means of forecasting in southern Africa (Goddard *et al*. 2001, Landman *et al*. 2001). As the understanding of ocean-atmosphere interactions grew and GCMs developed, skill in model simulations increased making it possible to predict inter-annual and inter-decadal climatic variability (Goddard *et al*. 2001). Subsequently many studies were undertaken on the link between ENSO and rainfall variability in South Africa (Goddard *et al*. 2001, Rautenbach & Smith 2001, Reason *et al*. 2006), focusing on the summer rainfall region as there was no coherent relationship between the winter rainfall region and ENSO (Rautenbach & Smith 2001, Reason & Jagadheesha 2005, Reason & Rouault 2005). Throughout the literature GCMs have been inclined to overestimate rainfall over South Africa as the models are inadequate in representing local scale features, or sub-grid processes, and reinforced the need for downscaling or recalibration of GCM simulations to a regional level in order to avoid these systematic biases (Goddard *et al*. 2001).

Initiatives to pool knowledge and develop seasonal forecasts were not limited to South Africa. Supported by the World Meteorological Organization (WMO), the various institutions that produced seasonal forecasts within the fourteen member countries of the Southern African Developing Community (SADC) region formed the Southern African Regional Climate Outlook Forum (SARCOF) (Klopper & Bartman 2003; Johnston *et al.* 2004; Hansen *et al.* 2011). The forum was designed to bring the various national meteorological services and users together to develop, distribute and discuss potential applications of a consensus forecast of rainfall and sometimes other variables for the coming season (Johnston *et al.* 2004). The main objective of the forum was to encourage technical and scientific capacity building in producing, disseminating and applying the season forecast information to weather-sensitive sectors, especially agriculture, of the various countries' economies (Johnston *et al.* 2004).

The availability of water in South Africa is the most important restriction to agricultural production (Breitenbach & Fenyes 2000; Klopper & Bartman 2003). Regions lacking sufficient water resources for irrigation depend solely on the variable seasonal rainfall. In these regions prior knowledge of the likely precipitation could lead to substantial improvements in national food security and in profits of commercial farmers (Johnston *et al.* 2004). It is thought that sectors such as these are prime candidates for the use of seasonal forecasts. A useful forecast is one which skilfully describes and quantifies the probability of each possible outcome throughout the full range of possibilities, from extremely wet to extremely dry seasons, for a small geographical region (Klopper *et al.* 2006). The information from a seasonal forecast is only valuable if the use of such information enhances the decision making of the user and improves overall risk management, ultimately increasing economic benefits (Klopper *et al.* 2006). Among commercial farmers in South Africa forecasts on a seasonal time-scale could influence decisions regarding the amount and timing of applications of input variables such as crop variety, fertilization rate, cultivar type, seeding rate, applied nitrogen rate and planting date (Klopper *et al.* 2006). Season forecasts could also assist with the planning of crop and soil management, increasing crop productivity whilst reducing the risk of agricultural producers (Johnston *et al.* 2004).

A wide spectrum of seasonal forecast information is available to the user communities in South Africa, with the South African Weather Service (SAWS) producing and distributing a seasonal forecast on a monthly basis (Johnston *et al.* 2004). The SAWS combines model output provided by international institutions (e.g. International Research Institute for Climate Prediction) with statistical regional models to produce 3-month probabilistic seasonal forecast (Klopper & Bartman 2003). The SAWS strives to improve seasonal forecasting by developing and improving modelling capabilities and dissemination channels (Klopper *et al.* 2006). However, the uptake of seasonal forecasts within the agricultural sector in South Africa has experienced mixed results. A number of agricultural institutions (e.g. The Agricultural Research Council's Institute for Soil, Climate and Water) use seasonal forecasts from SAWS to develop regular advisories for farmers (Johnston *et al.* 2004). Due to the large amount of media coverage and warnings issued of a developing El Niño event in 1997/98, a surge in the demand for seasonal forecasting products was noted by the SAWS between August

1997 and March 1998 (Klopper & Bartman 2003). Despite the 1997/98 El Niño event being the strongest on record, South Africa did not receive the below-average rainfall that was reported (Blench 1999; Dilley 2000; Kane 2009). The following season (1998/99) saw La Niña conditions prevail and again South Africa did not experience the predicted rainfall with dry and hot conditions occurring (Kane 2009). These highly publicized forecasts came under a large amount of criticism from the media and scepticism grew among many farmers with regards to the accuracy and skill of seasonal forecasts (Blench 1999; Dilley 2000).

There are a number of constraints preventing the realisation of the optimal value and use of these forecasts, including the way in which forecasts are produced, interpreted and applied (Klopper *et al*. 2006, Landman *et al*. 2010). Seasonal forecasting products are often misinterpreted by users and thought to have more meaning and, therefore, influence than forecasters initially intended (Johnston 2008). An example of this is that seasonal forecasts have often been interpreted as being deterministic for a specific location, and used in this way as a guide by sectors such as farming (Cane 2000; Johnston 2008). These interpretations, however, prove inconsistent and misleading as seasonal forecasts are probabilistic in nature and are not intended for direct use at a local scale (Cane 2000). Forecasts are often given as a percentage of normal rainfall, which also has been misinterpreted by farmers (Klopper *et al.* 2006). This term 'normal rainfall' has also been shown problematic as farmers have struggled to conceptualize what normal conditions are as rainfall is so variable. As forecasts are solely based on meteorically values, agricultural droughts (insufficient soil moisture to sustain crops) could occur well before a meteorological drought (a current rainfall value below a certain threshold) is recognised (Johnston 2008). The majority of forecasts disseminate rainfall information in the format of monthly and seasonal totals, which limits the usefulness of the forecast for farmers as this information can be ambiguous. Forecasts do not give information about the distribution of this rainfall across the month. If a seasonal forecast predicts a higher chance of above normal rainfall the farmer does not know whether this rainfall will occur in a few heavy rainfall events or many smaller events throughout the month, or whether this rainfall will occur at the beginning or end of the month and so will not be able to use the forecast as effectively as intended. Other common impediments to the uptake of seasonal forecasts among farmers in South Africa identified in the literature include; reliability, spatial resolution, timeliness, ambiguity, relevance and accessibility (Klopper & Bartman 2003; Klopper *et al.* 2006; Johnston 2008).Therefore, there is a need for tailored forecasts for specific users in specific climatic regions.

In an effort to avoid the complexities of conventional model derived seasonal forecasts a number of studies have attempted to use large-scale oceanic and atmospheric climate patterns as predictors for particular agricultural crop yields across the globe (Cane *et al.*

1994; Martinez *et al.* 2009; Bannayan *et al.* 2010; Unganai *et al.* 2013). In theory these studies would assess the relationship between various climate indices (predominately ENSO) and crop yields. These insights would then be used to examine the state of the atmosphere prior to the season and predict expected yields. In southern Africa studies have been focused on the influence of ENSO on maize yields (Cane *et al.* 1994; Unganai *et al.* 2013) with very little research focused on wheat production. No study has been conducted on the influence of climate indices on wheat yields in the Swartland region.

From the current state of the literature, a lack of understanding of the influence teleconnections has on wheat yields in evident. A need for tailored seasonal forecast information in the wheat production industry in the Swartland region is apparent. This study will assess the relationships between various teleconnection and wheat-specific rainfall characteristic indices and wheat yields in the Swartland. This research has been undertaken with the goal of assessing the feasibility of using large-scale oceanic and atmospheric climate patterns to predict wheat-specific rainfall characteristics in the Swartland. If significant correlations are found between the large-scale oceanic and atmospheric climate patterns and crop yields/wheat-specific rainfall characteristics, then, assuming the teleconnections can be skilfully predicted, there is the potential for skilful forecasts of rainfall characteristics and crop yield.

CHAPTER 3: METHODOLOGY

In this chapter a description of the methodology and approaches used to achieve the aim and objectives of the study is presented. The different sets of data utilized in the study are described and explained. Details of the analytical procedures implemented are articulated, and limitations of such analyses are discussed.

3.1 Statistical methods

All data handling, statistical methods and analysis used within this study were accomplished using the statistical programming language and environment known as '*R*'. *R* has been described as an integrated suite of software facilities for data manipulation, calculation and graphical display (Venables *et al.* 2013). This section describes the statistical methods used throughout the study.

3.1.1 Standardizing

A standard score (z) indicates the number of standard deviations a specific data point varies from the mean value (Eq.1). Standardizing is the process whereby all data points in a dataset are converted into standard scores. The standard deviation used for this study is defined in Eq.2. Standardized data is dimensionless; therefore, standardizing datasets provides an effective means to compared variables with differing scales. All standardizing was achieved through the use of the "scale" function within the "base" package in *R.*

$$z = \frac{x-\bar{x}}{\sigma} \qquad \text{(Eq.1)}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} \qquad \text{(Eq.2)}$$

3.1.2 Correlation

Correlation is an effective and widely used statistical method to measure the strength of linear dependence between two variables. Pearson's correlation coefficient (r) was used to measure the degree of association between various datasets to assess their linear relationship. Pearson's correlation coefficient (r) is defined by Eq.3.

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_1-\bar{y})^2}} \qquad \text{(Eq.3)}$$

Pearson's correlation coefficients (r) are on a scale that varies from -1 to +1. A positive (negative) coefficient indicates a positive (negative) linear relationship between the two variables, that is to say when one variable increases (decreases) so does the other. Correlation values of 0 indicate no correlation with complete correlation expressed as either -1 or +1. The Pearson's correlation coefficients were calculated using the "cor" function within the "stats" package in *R*. Significance of Pearson's correlation coefficients are tested using a hypothesis test. A null hypothesis that the correlation coefficient is zero (no relationship) is tested against the alternative hypothesis that a correlation exists (H_0: $\rho=0$; H_A: $\rho\neq0$). The significance is determined by using the critical values derived from the probability density function of the correlation coefficients (according to the degrees of freedom) for when the null hypothesis is true to either reject or accept the null hypothesis. For the purpose of this study only correlation coefficients that are significant at the 10% level ($P<0.1$) or higher are deemed significant. A significant correlation coefficient does not in itself prove a cause-effect relationship.

3.1.3 Linear detrending

Correlation measures the fit of two datasets to a linear regression. If the two time series are trending the measure of overall fit becomes misleadingly 'significant'. Linear detrending is a method commonly used to minimize spurious correlations. The linear detrending was accomplished by calculating the linear least square regression of each time series using the "lm" function within the "stats" package in *R*. The resulting residual values, the differences between the actual values and the predicted values, of the regression analysis are then used to represent the time series in the correlation analysis.

3.2 Datasets

3.2.1 Weather station data

Rainfall data was central to this study; therefore, careful consideration was placed on selecting the most appropriate data. Weather station data was favoured over gridded rainfall data as the latter failed to capture the variety of responses of local climate to large-scale forcing that exist within the relatively small study area, often resulting from the topography (as explained in Chapter 1).

The original daily weather station data was obtained from the Computing Centre for Water Research (CCWR) and the South African Weather Service (SAWS). The weather station data was subjected to a cleaning algorithm created by the Climate System Analysis Group based on the methodology developed by the Global Historical Climatology Network (GHCN) (Durre *et al.* 2010). Weather stations were screened to meet two criteria before they were legible for consideration for use within the study. The first criterion required the physical location of a weather station to fall within the pre-defined study area, whilst the second criterion required the weather station to have been in operation during the study's time period of interest (1st January 1980 - 31st December 2012) and to have no more than 10% of the daily rainfall record missing during the period.

Daily rainfall records from 24 weather stations passed the screening process and were utilized, a spatial distribution map of the weather stations is shown in Figure 3.1. Each station's record was aggregated to create a monthly record over the 33 year period.

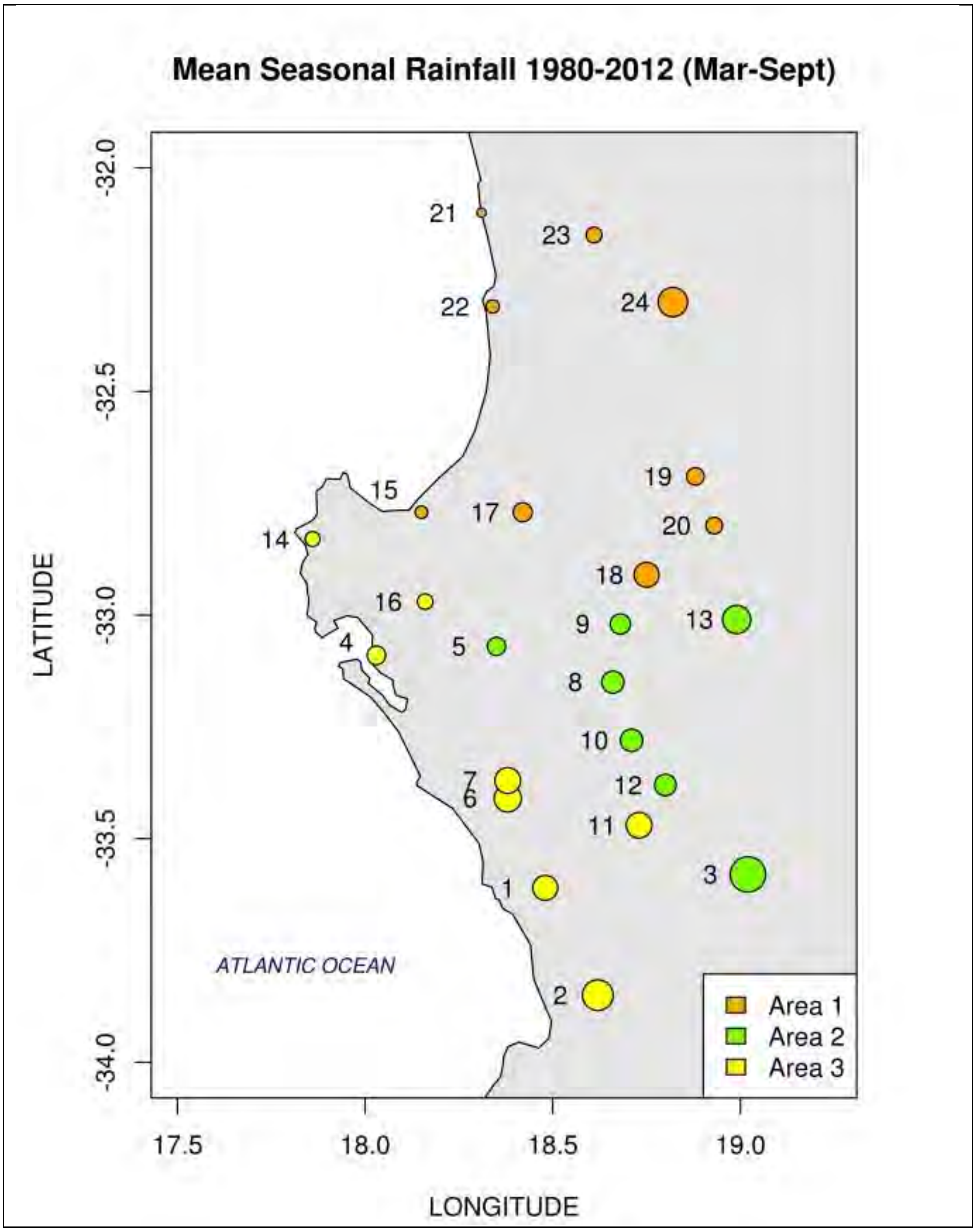

Figure 3.1: Map of the 24 stations used in the study. Circle colour indicates grouping areas (Area 1, 2 or 3). Circle size indicates the average amount of winter (Apr-Sept) rainfall; with larger circles indicating more rain.

These 24 monthly station records were standardized before being subjected to the agglomerative hierarchical Ward's clustering algorithm. The clustering was done to group stations with similar monthly rainfall distribution patterns. The cluster analysis was achieved by subjecting the 24 monthly station time series to the "*dist*" function within the "*stats*" package in *R.* This function calculated the Euclidean distances between each of the standardized station time series. The resulting matrix was then used in the hierarchical Ward's clustering algorithm, which was performed by the "*hclust*" function within the "*stats"* package in *R*. The Ward's algorithm minimises the variance within each cluster whilst maximising the variance between the different clusters, making it a useful approach to group weather stations having similar temporal rainfall distributions. A linkage distance of 16 was used, creating three clusters (Figure 3.2), which will be referred to as Area 1, 2 and 3 (Figure 3.1). The daily station rainfall records from 1980 to 2012 within each of these three areas were averaged to create a single daily rainfall record for each area. This became the core rainfall datasets used in this study.

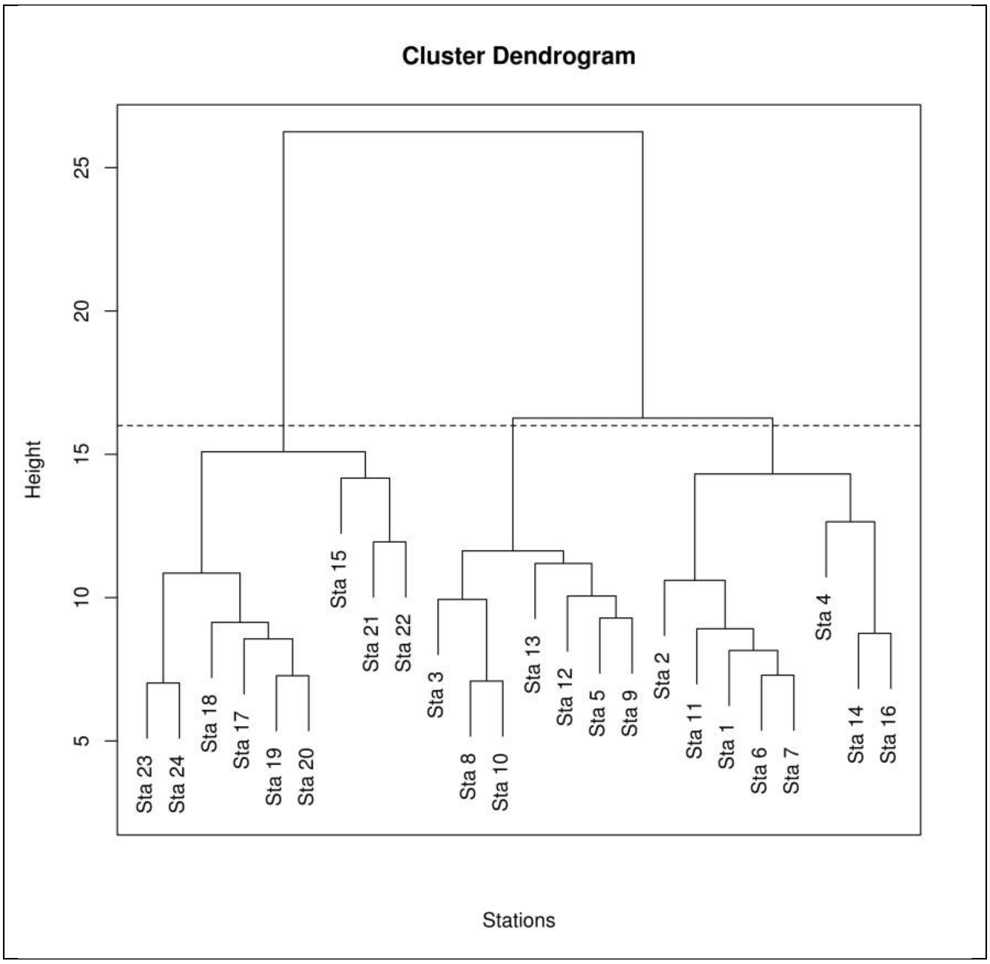

Figure 3.2: Cluster dendrogram of the hierarchical Ward's clustering performed on the 24 monthly station records. Dotted line indicates the cutoff line.

In an attempt to provide more relevant and tailored rainfall information that could possibly prove of greater value to wheat farmers than rainfall totals alone, additional wheat-specific rainfall characteristics were extracted from each of the three homogeneous rainfall areas' daily datasets (area-averages) to create "wheat-specific" rainfall characteristic indices. Five additional rainfall characteristics believed to have some value to wheat farmers were extracted to create monthly 'wheat-specific' rainfall characteristics indices. The five monthly indices were:

1. *Wet days*: The number of days, within a particular month, which received greater than or equal to 2mm of rain.
2. *'Good' rainfall*: The number of days, within a particular month, which received greater than or equal to 10mm of rain.
3. *Heavy rainfall*: The number of days, within a particular month, which received greater than or equal to 25mm of rain.
4. *Percentage 'good' rainfall*: The percentage of *wet days* that were classified as *'good' rainfall* within a particular month *('good' rainfall/wet days**100).
5. *Dry Dekads*: An index indicating the number (out of 3) of dekads (10 day periods) within a particular month that received less than 10mm of rain.

The daily rainfall records from the three areas were used to create a dekadal (10 day) rainfall index from 1980 to 2012. Each month was split into three dekads with the third dekad varying in length depending on the number of days in a particular month (i.e. 8, 9, 10 or 11 days). A dekadal rainfall index was created in an effort to gauge rainfall distribution throughout the wheat growing season.

3.2.2 Wheat yield data

For various reasons, substantial wheat yield data from the Swartland region proved difficult to obtain. The wheat produced by farmers is bought by farming cooperatives (commonly known as co-ops) and sold by the co-ops to various wheat mills in the region. Two major farming co-ops operate within the Swartland region – namely, Kaap Agri and Moorreesburgse Koringboere (MKB). The data for areas planted and total wheat produced were gleaned from these two wheat farming co-ops. The length of these two records varied, with the MKB's 17 year record from 1994-2010 proving the most substantial. The Kaap Agri wheat yield record only spanned a ten year period (2000-2010), which proved too limiting and not extensive enough for this study and, therefore, was discarded. The lack of digitized data and the merging of co-ops over the past couple of decades was the explanation given by the two Swartland co-ops to explain the brevity of the records. Although lengthier records of average wheat yields for the entire Western Cape (and South Africa) are available, they do not discern between the two growing regions (Swartland and Rûens) and, therefore, were not suitable for the study.

Fluctuations within the wheat production record, due to year-to-year variations in the total area planted, made the record unsuitable for analysis. This was overcome by dividing the wheat production data by the area planted to create a wheat yield record in tonnes per hectare.

As mentioned above (Chapter 2), an exponential increase in the productivity of wheat farmlands (yield) over the past 40 years occurred in South Africa, due to mechanisation and improved farming practices. The exponential increase skewed the yield data records and required detrending before it could be used for analysis. The 1970-2012 wheat yield record for South Africa was used to determine the exponential trend over the 43 year period for the country. The national yield trends were used, as opposed to the Swartland yield trends themselves, to negate any potential bias that could be present in the Swartland data due to locale specific factors. The exponential trend was calculated using the least squares fit method. This exponential trend was removed from the MKB wheat yield series by subtracting the predicted values from 1994 to 2010 of the exponential trend from actual values of the MKB yield data to create the detrended yield data.

Finally, the linear trends were removed from the detrended yield data as to not influence the correlation analysis. The detrended MKB record was subjected to the linear detrending, producing the wheat yield record, which became the core wheat yield data to be used in the analysis.

3.2.2 Climate indices data

A number of teleconnections have been linked to the winter rainfall of the Western Cape region of South Africa (seen in Chapter 2). This study investigated three of these potential teleconnections – namely, El Niño-Southern Oscillation (ENSO), South Atlantic sea surface temperatures (SSTs) and the Antarctic Oscillation (AAO). Eight monthly indices were used to represent the three teleconnections (ENSO and South Atlantic SSTs – three each; AAO – two). Multiple indices were used to represent each of the teleconnections in an attempt to create a robust analysis that captures the nature of a teleconnection and not any potential bias of a particular index.

The first of the three indices representing ENSO was the monthly Nino3.4 Index[1] (5°S–5°N/120°–170°W), identical to the index used by Philippon *et al.* (2011). This Index is based

[1] http://climexp.knmi.nl/getindices.cgi?WMO=UKMOData/hadisst1_nino3.4a&STATION=NINO3.4&TYPE=i&id=someone@somewhere

on the Hadley Centre Sea Ice and Sea Surface Temperature data set (HadISST) (Rayner *et al.* 2003) available from the Royal Netherlands Institute of Meteorology (KNMI) climate explorer (van Oldenborgh & Burgers 2005). These monthly values were averaged for overlapping trimestral periods, i.e. January, February and March (JFM); February, March and April (FMA) etc. The second ENSO index used was the Ocean Nino Index[2] (ONI) based on the Extended Reconstructed Sea Surface Temperature version 3b (ERSST.v3b) dataset (Smith *et al.* 2008) and available from the Climate Prediction Center (CPC) at National Centers for Environmental Prediction (NCEP), one of the National Oceanic and Atmospheric Administration's (NOAA) National Weather Services (NWS). Despite also using the Nino3.4 region (5°S–5°N/120°–170°W), the ONI differs from the Nino3.4 Index as it uses a three month running mean of the ERSST.v3b SST anomalies, based on centred 30-year base periods updated every five years. This approach was adopted by the CPC in order to overcome the significant warming trend in the Niño3.4 region since 1950, which masked the interannual ENSO variability when using the conventional single fixed 30-year base period. For both Nino3.4 Index and ONI, El Niño and La Niña events were defined to occur when the anomaly of at least five consecutive over-lapping trimester periods were respectively above 0.5 and below -0.5 standard deviations. The final ENSO index, the Southern Oscillation Index[3] (SOI), is one that focuses on the atmospheric circulation over the south equatorial pacific (known as the Walker Circulation). The SOI, obtained from the CPC, is computed using monthly mean sea level pressure anomalies (departures from the 1981-2010 base period) at Tahiti and Darwin (Tahiti – Darwin). Similar to the Nino3.4 Index the SOI monthly values were then averaged for overlapping trimestral periods.

South Atlantic SST indices were created for this study as there are no existing or commonly used indices to date. As mentioned above (Chapter 2), previous studies have identified SST patterns across the South Atlantic (between the eastern coastline of South America and just south of the western coast of Southern Africa), which have been associated with anomalously wet and dry winters in the South Western Cape (SWC) (Figure 3.3) (Reason *et al.* 2002; Reason & Jagadheesha 2005). From these studies two regions were identified, the first being the area of cyclogenesis for mid-latitude cyclones that make landfall in South Africa (29°-45°S, 48°-64°W). This area is found off the coastline of Brazil, Uruguay and Argentina and will be referred to as the South Western Atlantic (SWA). The second region (36°-44°S, 0°E-18°W), found in the Central part of the South Atlantic (SCA), was thought to influence the latitudinal track of mid-latitude cyclones (Reason *et al.* 2002; Reason & Jagadheesha 2005). Averaged monthly SST values from the ERSST.v3b dataset (Smith *et*

[2] http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml
[3] http://www.cpc.ncep.noaa.gov/data/indices/soi

al. 2008) over the 1980-2012 period were obtained for both areas (SWA[4] and SCA[4]) from KNMI climate explorer. Standardized anomaly time series were created from the two monthly SST datasets each of which were then averaged to create overlapping trimester indices, named the South Western Atlantic SST Index (SWAI) and the South Central Atlantic SST Index (SCAI). The SWA and SCA standardized anomaly time series were also used to create a South Atlantic Dipole Index (SADI). The methodology used by the CPC to create the SOI was followed to create the SADI, the equation for which is seen in Eq.4:

$$SADI = \frac{SWA-SCA}{\sqrt{\frac{\sum_{i=1}^{N}(SWA-SCA)^2}{N}}} \qquad \text{(Eq.4)}$$

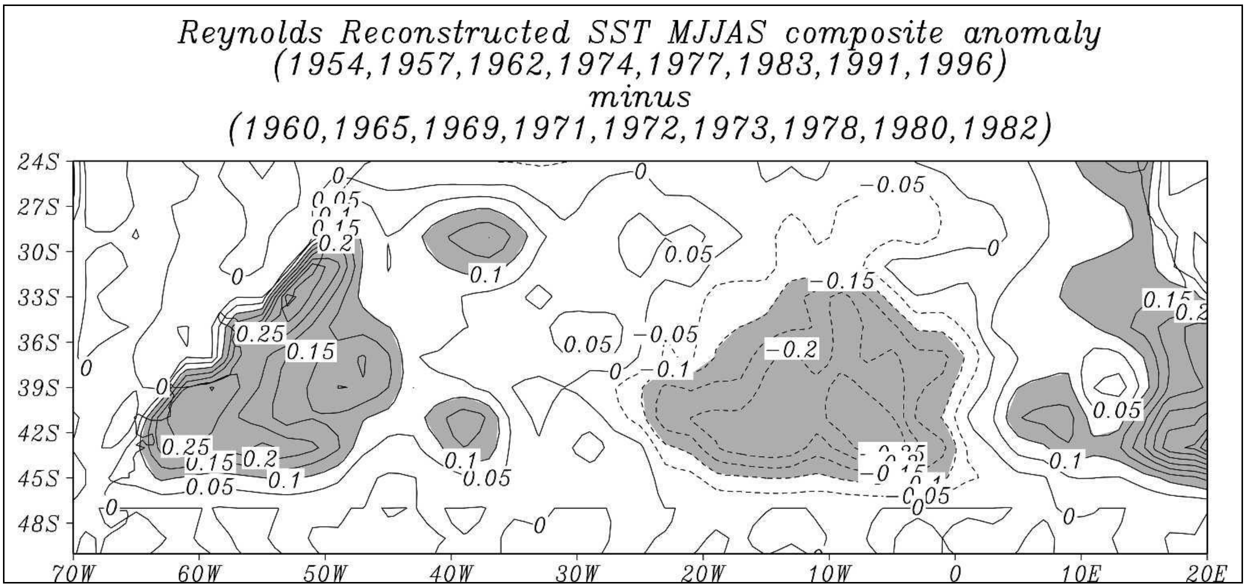

Figure 3.3: Wet minus dry South Western Cape winter composite SST pattern. Contour interval is 0.05°C. ***Source***: *Reason et al. (2002).*

The SWA and the SCA values used in the equation are standardized values, whilst N equals the number of months from 1980 to 2012. Previous studies suggest wet winters are associated with anomalously warmer SSTs in the SWA and anomalously cooler SSTs in the SCA region (Reason *et al.* 2002; Reason & Jagadheesha 2005), which would result in a positive SADI value. The monthly SADI was averaged for each trimester and used in the analysis.

The final two climate indices to be used in the study were the Antarctic Oscillation Index (AAO[5]) and the Southern Hemisphere Annular Mode Index (SAM[6]). Both indices attempt to capture the same feature, as the AAO is synonymous with the SAM, and only differ in their definitions. The AAO Index from 1980 to 2012 was obtained from the CPC, who created the

[4] http://climexp.knmi.nl/select.cgi?id=someone@somewhere&field=ersstv3b
[5] http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/aao/monthly.aao.index.b79.current.ascii
[6] http://www.nerc-bas.ac.uk/icd/gjma/sam.html

Index by applying the Empirical Orthogonal Function (EOF) to the monthly mean 700hPa height anomalies, calculated from the NCEP/NCAR reanalysis dataset (Kalnay *et al* 1996), poleward of 20°S. The SAM Index, however, is calculated by using weather station data and compares pressure differences between Antarctic coastal stations with stations in the middle latitudes, the methodology for which is outlined by Marshall (2003). The monthly SAM Index from 1980 to 2012, along with the AAO Index, was converted to the overlapping trimester format. The trimonthly format is used to accommodate the delays between remote indices and local impacts, as fluctuations in the various teleconnections propagate around the globe.

3.3 Data analysis

3.3.1 Association of precipitation with wheat yields

The purpose of this section of the analysis was to investigate the relationships between wheat-specific rainfall characteristics and wheat yields in the Swartland region, fulfilling the first objective of the study. This was done in order to gain an understanding of which rainfall characteristics were important to wheat production. Due to the limitations imposed by the wheat yield data the analysis focused on the 1994-2010 period and used the detrended MKB wheat yield record. The Area 2 rainfall record was utilized for this analysis as this area contained the stations in and surrounding the Moorreesburg farming district from which the MKB co-op receives its wheat.

3.3.1.1 Winter rainfall

The rainfall and the five additional rainfall characteristic records were aggregated to create winter (April to September) rainfall indices from 1994 to 2010. The winter rainfall indices were subjected to the linear detrending before they were compared against the detrended yield data using Pearson’s correlation analysis. The resulting correlation coefficients were tested to determine statistical significance.

3.3.1.2 Seasonal rainfall

The winter period was split into early (April to June) and late (July to September) seasonal periods. The rainfall and rainfall characteristics records were aggregated to create seasonal rainfall indices from 1994 to 2010. The seasonal rainfall indices were removed of any linear trends and then correlated against the detrended wheat yield data. The resulting correlation coefficients were tested to establish their statistical significance.

Seasonal rainfall and rainfall characteristic indices along with the wheat yield record were standardized so as to categorise the data into three categories – namely, low (one standard deviation below the mean), normal (within one standard deviation of mean) and high (one standard deviation above the mean). The categorical data allowed for the evaluation of whether certain combinations of early and late seasonal rainfall produced particular yields. From this analysis six years were selected according to yield for further investigation, two years from each of the categories (low, normal and high yield).

3.3.1.3 Monthly rainfall

The temporal scale of the rainfall data was reduced to create monthly rainfall indices (April to September). These indices were each subjected to the linear detrending and correlated against the detrended yield data. The resulting correlation coefficients were tested to determine statistical significance. The mean monthly rainfall distribution was calculated by averaging the individual months over the 17 year period from 1994 to 2010 and used to compare with individual years.

3.3.1.4 Dekadal rainfall and wheat thresholds

This analysis investigated the relationship between yield and the distribution of rainfall through the use of farmer specified thresholds, which were thought to impact wheat. On 18 April 2012 discussions were held with MKB experts regarding the current farming management practices and possible future farming operations of wheat production in the Moorreesburg area. The discussions were followed up by a validation workshop on 10 September 2012 at which MKB experts and union members, wheat farmers from the area and agricultural researchers were in attendance. Key elements of climate change impacts and adaptation responses were highlighted as well as threshold climatic and weather values thought to damage crops and affect yields.

The three thresholds established at the workshop:

1. Minimum rainfall before planting: 50mm over six weeks
2. Minimum rainfall during growing season (June to August): 10mm per dekad
3. Minimum rainfall during September (regarded as critical by farmers): 10mm per week

The thresholds required converting to allow for evaluation against the dekadal rainfall data. For the first threshold it was necessary to define a planting date so as to ascertain the six weeks prior. Through dialog with farmers from the Swartland region, mid to late May was described as the optimum planting period; therefore, the third dekad of May was used in this study as the date of planting. The four dekad period from the second dekad of April through to the second dekad of May (40 day period) become the six week (42 day) period prior to planting specified in the first threshold. The second threshold period was extended to include the third dekad of May (the first ten days after planting) to create a continuous 'crop season' for analysis (second dekad of April to the end of September). Threshold 3 was converted from 10mm per week (40mm per September) to 14mm per dekad (42mm per September).

The yearly yield data was categorized into five categories – namely, low (one standard deviation below the mean), normal-low (between half a standard deviation and one standard deviation below the mean), normal (within half a standard deviation of mean), normal-high (between half a standard deviation and one standard deviation above the mean) and high (one standard deviation above the mean). The thresholds were examined against the dekadal rainfall record for six individual years and the corresponding categorical yields. The results were used to create a prediction model (see Chapter 4 for further explanation), which was tested on the remaining 11 years.

3.3.2 Association of climate indices with wheat yield

The procedure for assessing the relationships between global teleconnections that may influence climate variability in the Swartland and wheat yields, the second objective of the study, is described in this section. The available wheat yield data from the MKB cooperative limits the range of this analysis to the 1994-2010 period.

3.3.2.1 Correlation analysis

To determine whether any of the climate indices could be used to directly predict wheat yields in the Swartland, the degrees of association between the eight climate indices (Nino3.4, ONI, SOI, SWAI, SCAI, SADI, AAO and SAM) and the wheat yields were measured using Pearson's correlation coefficients. The trimonthly climate indices from 1994 to 2010 were removed of any linear trends, which would have influenced the Pearson pairwise correlation analysis. The resulting correlation coefficients were tested to determine statistical significance.

3.3.2.2 Large-scale surface and atmospheric circulation pattern analysis

In order to gain a better understanding of the correlations observed between the climate indices and the wheat yields, various atmospheric fields (surface pressure, sea surface temperature and surface wind) were used to create composite anomaly plots for years of extreme yield. The years to have experienced the four highest and four lowest yields (all greater than 0.5 standard deviations away from the mean) were identified. The climatology's for the various atmospheric fields were established over the 1981-2010 period. The anomaly of each year over either the winter period (April-September) or early and late seasonal (Apr-Jun, Jul-Sept) periods was calculated from the long term mean (1981-2010) of the various atmospheric variables and averaged over the high and low yield years. The composites were then created by subtracting the average anomaly of the low yield years from that of the high yield years. The climatic composite plots were created using NCEP reanalysis data via an online research and development application[7] created by the Physical Sciences Division (PSD) of the Earth System Research Laboratory (ESRL), a branch of the NOAA.

3.3.3 Association of rainfall characteristics with climate indices

This section of the analysis was designed to determine whether any connections existed between various climate indices and rainfall characteristics within the three areas of the Swartland region over the 1980-2012 period. Eight climate indices representing three teleconnections (ENSO, South Atlantic SSTs and AAO) and six rainfall characteristic indices from each of the three areas were used. All the climate and rainfall characteristic indices were in overlapping trimonthly format and subjected to linear detrending before analysis.

3.3.3.1 Correlation analysis

The three ENSO indices (Nino3.4, ONI and SOI), two AAO indices (AAO and SAM) and three South Atlantic SST indices (SADI, SCAI and SWAI) were correlated against the six wheat-specific rainfall characteristic indices (*Rainfall, wet days, 'good' rainfall, percentage 'good' rainfall, heavy rainfall* and *dry dekads*) from each of the three areas. The statistical significance of the Pearson correlation coefficients were established and tabulated. Correlations were deemed significant at the 10% level ($\rho<0.1$). The significant correlations in each area were tallied for the additional rainfall characteristic indices in an effort to condense the information for presentation purposes.

Finally all the correlation data was condensed into one representative table for each of the three areas. The summation table used a weighting system so as not to over or under represent a particular teleconnection. For further information regarding the methodology of the summation table see Chapter 4.

3.3.3.2 Large-scale surface and atmospheric circulation pattern analysis

In an effort to validate particular significant correlations observed between the rainfall indices from the three areas and the climate indices, various atmospheric fields (sea surface temperature and geopotential height [GpH]) were used to create composite anomaly plots for years of anomalously wet minus dry (defined as above and below half a standard deviation away from the mean respectively) trimonthly periods. The composite plots examined periods for which the climate indices showed correlation and for years identified by the particular

[7] http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl

rainfall trimonthly period of interest. The climatic composite plots were created using NCEP reanalysis data via an online research and development application created by the PSD of the ESRL, a branch of the NOAA.

3.4 Data limitations

In order to perform a comprehensive and valid study it is important to acknowledge the limitations that are imposed by various factors. When working with observational data there is always an element of error due to the inherent variability within the variables being measured and the measurement processes themselves. As a result, the observed station rainfall data will possess both systematic and random errors, although these errors are assumed to be very small and, therefore, insignificant.

Data from a particular weather station is assumed to be a fair representation of the conditions experienced in the surrounding area. However, this is not always a correct assumption as the environment around a particular station may change over time often due to anthropogenic influences, such as the expansion of urban areas.

The relatively short length of the wheat yield record used in this study (17 years) is a limitation when attempting to infer statistical relationships with either large-scale ocean and atmospheric climate patterns or rainfall, which are known to contain elements of decadal variability which may bias any derived correlations. Additionally the wheat data received from the different co-ops are estimations and not exact values. All agricultural production data is based on estimations, as to measure exact values is not a feasible option. Despite the estimations being very thoroughly calculated, they are still estimations and, therefore, contain an unknown degree of uncertainty. The wheat yield data is assumed to be a fair representation of the yield from Area 2; however, the exact number and locations of the farms that deliver to the co-operative, from which the wheat yield data was obtained, are unknown.

There are many factors that influence wheat yields, including factors which are not yet known. Therefore, despite the need to remove the effects of mechanisation and improved farming techniques from the regional wheat yield datasets, the detrending process had the potential to remove the effects of additional influences that may have contributed to the decadal increase.

Despite the effectiveness of correlation it is worth noting some assumptions made when using the statistical technique. Correlation assumes the two variables are independent or isolated systems, which is often not the case, and so could be misleading. The correlation analysis used in this study assumes the variables are normally distributed and that the relationship between the two variables is linear. It is possible for two variables to show correlation by coincidence, which is why the significance of the correlations are evaluated and only coefficients significant at the 10% level were used. Importantly correlation does not imply causation and so values were carefully assessed for feasibility and utilized accordingly for the purpose of this study.

CHAPTER 4: RESULTS

This chapter presents the results from the study in three sections, each of which will cover one of the core objectives of this thesis. The first section of this chapter elaborates on the relationship between wheat yields in the Swartland region and rainfall characteristics, at various temporal scales. The relationships between global teleconnections, which may influence climate variability in the Swartland, and wheat yields are presented in the second section. Evidence evaluating any apparent influence large-scale modes of climate variability may have on wheat-specific rainfall characteristics will be shown in the third and final section.

4.1 Association of precipitation with wheat yields

4.1.1 Winter rainfall

Initially the relationship between *rainfall* and wheat yield data in the Swartland was investigated. The winter *rainfall* (April-September) and the detrended wheat yield data (1994-2010) from Area 2, the only area for which wheat yield data existed, are shown in Figure 4.1. The wheat yield data shows a significant positive correlation with the winter *rainfall* at the 10% significance level ($r=0.424$, $\rho<0.1$) (Figure 4.2a). The two years, 2003 and 2004, that experienced "crop failure" with yields of 65% and 52% below the annual average respectively, occurred during years that experienced the two lowest winter rainfall amounts. The third lowest winter rainfall, however, occurred in 2000 with a mere 12mm more winter rainfall than 2003 and yet 2000 experienced above normal yield. Similarly, in 1999 we see the second highest recorded wheat yield (37% above normal) occurring during a year with below average rainfall. The seemingly wet years of 2007 and 2008, which recorded the two highest winter rainfall amounts, produced normal wheat yields. The *rainfall*-yield relationship can be seen more clearly in the scatter plot diagram showing the standardized wheat yield and winter rainfall data (Figure 4.2a). These results infer that the total winter rainfall amount may not be the critical predictor in determining the wheat yield, justifying a more in-depth analysis into the *rainfall*-wheat yield relationship.

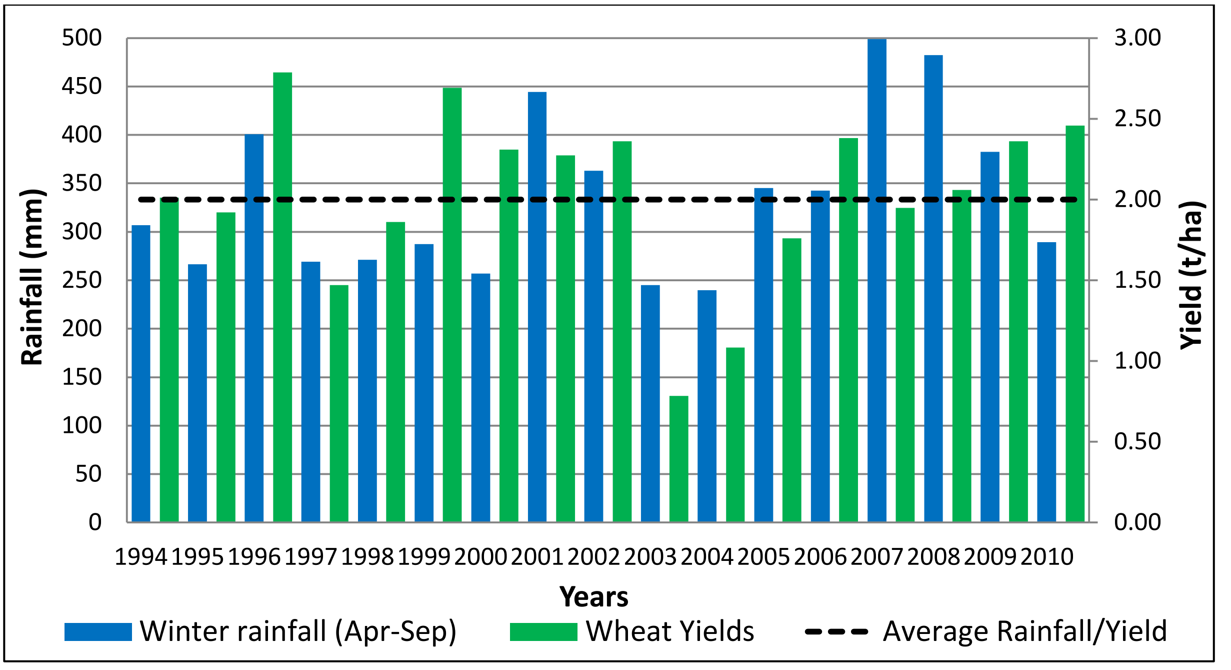

Figure 4.1: Winter rainfall (Apr-Sept) (blue bars) and wheat yields (green bars) over the 1994-2010 period. Dashed black line indicates the mean of both the rainfall and yield over the period.

The five additional winter rainfall characteristics (April-September); the number of *wet days* (daily rainfall >2mm), the number of *'good' rainfall* events (daily rainfall >10mm), the *percentage of 'good' rainfall* events to the number of *wet days*; the number of *heavy rainfall* events (daily rainfall >25mm) and the number of *dry dekads* (dekad rainfall <10mm), were then compared with the wheat yield. Scatter plots between the three winter rainfall characteristics to show significant correlation ($\rho<0.1$) with the yield can be seen in Figure 4.2 (b-d). Similar to the winter *rainfall* and wheat yield relationship, the three rainfall characteristics show a positive correlation (negative for *dry dekads* Index) with wheat yield; however, there are a number of years, which seem to oppose these trends These findings indicate that rainfall characteristics on a winter seasonal scale can be considered a determining factor of wheat yield; however, they are not the only determining factors.

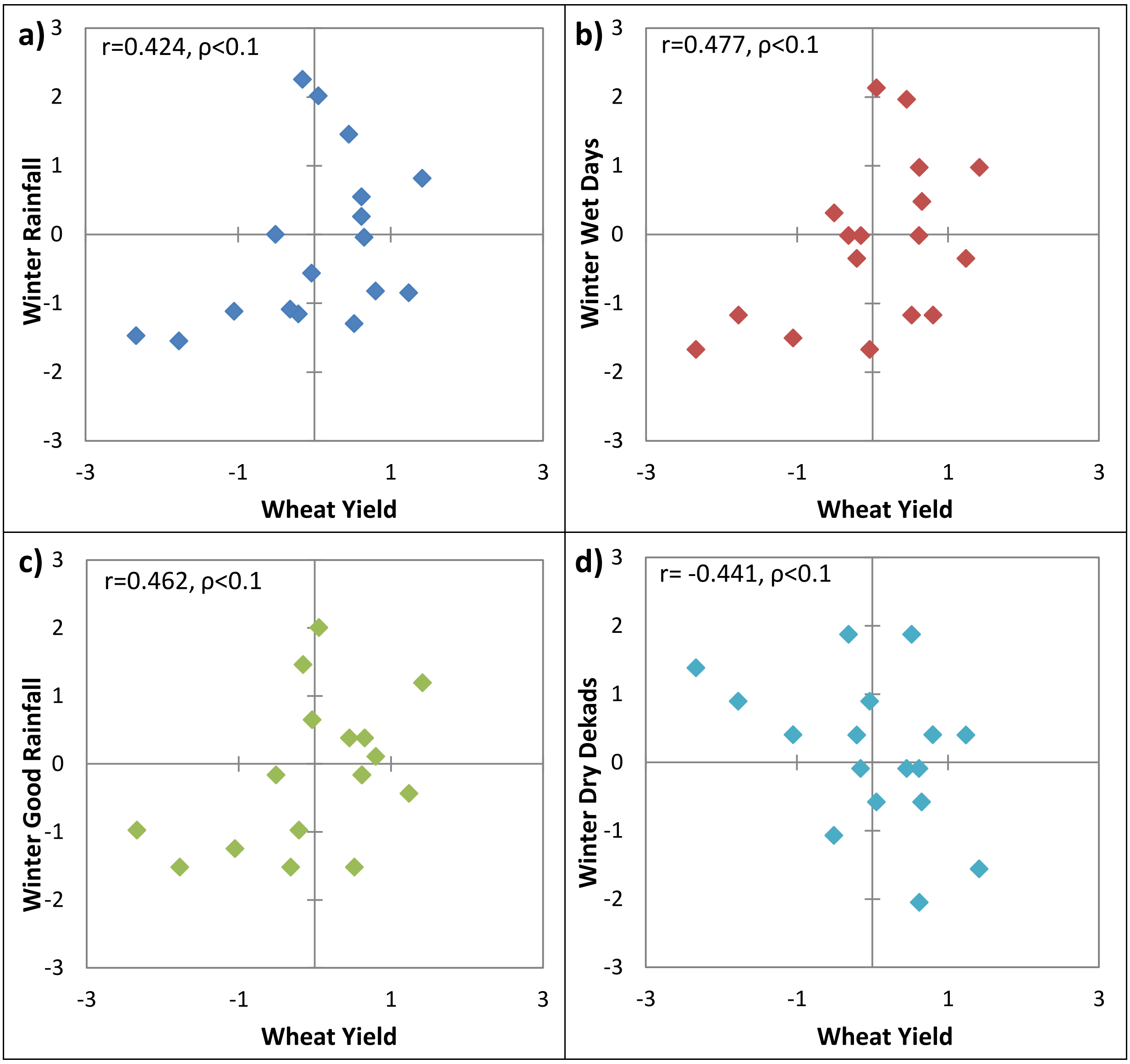

Figure 4.2 (a-d): Yearly standardized values of wheat yield and **a)** winter *rainfall*, **b)** the number of *wet days* during winter, **c)** the number of *'good' rainfall* events over winter and **d)** number of *dry dekads* over the winter period from 1994-2010.

4.1.2 Seasonal rainfall

The attention turns to the impact of early and late seasonal *rainfall* on wheat yield. The early and late seasonal periods are defined as the three month periods of April to June (AMJ) and July to September (JAS), respectively. The deviations of rainfall for each seasonal period from its mean over the period 1994 to 2010, together with the yield variation, are shown in Table 4.1. The highlighted values indicate percentages, which are less (red) or greater (blue) than one standard deviation from the mean. Looking at the years for which extreme rainfall occurred (highlighted values) during the early (late) season only one (two) out of the four (six) extreme events coincide with an extreme wheat yield event. Not surprisingly, early and late seasonal rainfall showed little correlation with wheat yield (Table 4.2) with coefficients failing to be significant at the 10% significance level.

Table 4.1: Deviations of early (Apr-Jun) and late (Jul-Sep) seasonal *rainfall* and wheat yields shown in percentage of mean. Values which exceed one standard deviation below (red) and above (blue) the mean are highlighted.

Year	Rainfall (% of mean)			Wheat Yield
	AMJ	JAS	Total	
1994	24.0%	-47.0%	-11.1%	-0.9%
1995	-30.5%	-15.1%	-22.9%	-5.4%
1996	-10.3%	42.8%	16.0%	37.2%
1997	5.6%	-50.4%	-22.1%	-27.6%
1998	-7.4%	-35.9%	-21.5%	-8.3%
1999	-15.7%	-17.9%	-16.8%	32.6%
2000	-57.2%	6.6%	-25.6%	13.7%
2001	-22.1%	80.4%	28.7%	12.0%
2002	0.4%	10.0%	5.1%	16.3%
2003	-67.0%	9.7%	-29.0%	-61.4%
2004	-25.4%	-35.8%	-30.5%	-46.7%
2005	10.7%	-11.0%	0.0%	-13.3%
2006	7.2%	-9.0%	-0.9%	17.2%
2007	78.1%	10.1%	44.4%	-4.0%
2008	-7.8%	88.1%	39.7%	1.4%
2009	28.4%	-7.3%	10.7%	16.2%
2010	12.6%	-45.7%	-16.2%	21.1%
Std Dev	29.5%	36.0%	19.7%	26.3%

Table 4.2: Pearson's correlation coefficients between wheat yields and rainfall characteristics for the early (Apr-Jun) and late (Jul-Sep) seasonal periods, over the 1994-2010 period. Values in bold indicate significance at the 10% level (ρ<0.1).

Rainfall Characteristics	Seasonal Periods	
	Early (AMJ)	Late (JAS)
Rainfall	0.286	0.244
Wet Days	0.339	0.339
'Good' Rainfall	**0.522**	0.097
% 'Good' Rainfall	**0.445**	0.014
Dry Dekads	-0.284	-0.369

Table 4.2 shows the correlation between seasonal rainfall characteristics and yield with correlations significant at the 10% significance level in bold. Only the number of *'good' rainfall* events (r=0.522, ρ<0.05) and the *percentage of 'good' rainfall* events to number of *wet days* (% *'Good' rainfall*) (r=0.445, ρ<0.1) during the early season showed any significant correlations with yield. The positive correlations indicate years of higher than average yield coincide with years, which experience more frequent 'good' rainfall events or a higher proportion of 'good' rainfall events to the number of wet days during the April to June period. The correlation coefficients between seasonal rainfall characteristics and yield are generally lower than those between winter rainfall characteristics and yield.

The data in Table 4.1 was categorized into low (one standard deviation below the mean), normal (within one standard deviation of mean) and high (one standard deviation above the mean). The possible combinations of low, normal and high rainfall in each three month seasonal period and the resultant yields are shown in Table 4.3, with each year being allocated to a combination. This was done in an attempt to evaluate whether certain combinations of early and late seasonal rainfall produced a particular yield. All years with low rainfall during either the early or late seasonal periods experienced low or normal yields. Similarly, all years with high rainfall during either of the seasonal periods experienced high or normal yield. However, years with normal rainfall during both early and late seasons experienced a wide variety of yields ranging from low to high.

Table 4.3: Seasonal rainfall categorical combinations, and year specific categorical yield from 1994 to 2010. For category definitions, see key.

RAINFALL		YIELD		
AMJ	JAS	L	N	H
L	L			
L	N	**2003**	**1995**,2000	
L	H			
N	L	1997	1994,2010	
N	N	**2004**	1998,2002,2005,2006,2009	**1999**
N	H		2001,2008	**1996**
H	L			
H	N		**2007**	
H	H			

Key
Low (L) ≤ -1 Std Dev%
Neutral (N): -1 Std Dev%<N<1 Std Dev%
High (H) ≥ 1 Std Dev%

In an attempt to further the understanding of the *rainfall*-wheat yield relationship, six specific years were selected for further analysis: 2003, 2004 (low yield), 1995, 2007 (normal yield) and 1996, 1999 (high yield). Examining the seasonal rainfall characteristics of a particular year together may help to explain yield that was achieved. The six specific years, their total seasonal and winter rainfall characteristics and the corresponding yields are shown in Table 4.4. Very low rainfall during the early season (seven out of nine dekads receiving less than 10mm), with normal rainfall in the late season led to low yield in 2003, with the same combination producing normal yield in 1995. Slightly lower than average rainfall in the early season followed by high rainfall (1996) and slightly below rainfall (1999) in the late season both produced high yield. The wettest season throughout the six years occurred during the early season of 2007 with the 18 *wet days*, 55% of which were classified as *'good' rainfall* events, producing 310.5mm of rain. This was followed by a late season of normal rainfall but saw a year of normal yield. To investigate in more detail these seasonal variations intra-seasonal rainfall characteristics were examined.

Table 4.4: Total seasonal rainfall characteristics of six years with associated yields.

Year	Rainfall Characteristic	Season		Yield	Year	Rainfall Characteristic	Season		Yield
		AMJ	JAS				AMJ	JAS	
1995	*Rainfall (mm)*	121.3	145.2	N	2003	*Rainfall (mm)*	57.5	187.5	L
	Wet Days	16	19			*Wet Days*	8	19	
	'Good' Rain	4	4			*'Good' Rain*	1	7	
	% 'Good' Rain	25.0%	21.1%			*% 'Good' Rain*	12.5%	36.8%	
	Dry Dekads	4	4			*Dry Dekads*	7	3	
1996	*Rainfall*	156.4	244.3	H	2004	*Rainfall (mm)*	130	109.8	L
	Wet Days	16	27			*Wet Days*	16	14	
	'Good' Rain	7	9			*'Good' Rain*	3	3	
	% 'Good' Rain	43.8%	33.3%			*% 'Good' Rain*	18.8%	21.4%	
	Dry Dekads	4	0			*Dry Dekads*	4	5	
1999	*Rainfall (mm)*	147.1	140.4	H	2007	*Rainfall (mm)*	310.5	188.2	N
	Wet Days	16	19			*Wet Days*	18	19	
	'Good' Rain	7	3			*'Good' Rain*	10	7	
	% 'Good' Rain	43.8%	15.8%			*% 'Good' Rain*	55.6%	36.8%	
	Dry Dekads	4	4			*Dry Dekads*	4	3	
Mean	*Rainfall (mm)*	166.5	168.3						
	Wet Days	17.5	18.8						
	'Good' Rain	5.7	5.4						
	% 'Good' Rain	31.6%	26.6%						
	Dry Dekads	3.9	3.5						

4.1.3 Monthly rainfall

The temporal scale of the rainfall data was further reduced from seasonal to monthly. Table 4.5 contains the correlation coefficients between the monthly rainfall characteristics and the yield. The only significant correlation observed between monthly *rainfall* and yield is the positive correlation between May rainfall and yield ($r=0.578$, $\rho<0.025$). Significant positive relationships occur between yield and number of *wet days* ($r=0.589$, $\rho<0.025$) during May and between yield and the number of *'good' rainfall* events ($r=0.428$, $\rho<0.1$) during May. *Dry dekads* shows a significant negative correlation with wheat yield ($r= -0.518$, $\rho<0.05$) during

May. This suggests that years of higher yield coincide with years that experience a wetter month of May (which may partly reflect wetter early season totals), with an increased number of wet days and 'good' rainfall events and fewer dry dekads occurring during the month. The month of May is traditionally the planting period of wheat crops in the Swartland. Interestingly the correlations suggest years of higher yield also coincide with years which experience a higher percentage of 'good' rainfall events to total number of wet days during the month of April ($r=0.626$, $\rho<0.01$), i.e. fewer more intense rainfall events. This result may suggest the importance of soil moisture to the wheat crop as more intense rainfall events will cause greater infiltration rates than weaker events. The number of *dry dekads* during the month of July also shows a negative significant correlation with yield. Roughly 40-70 days into the crop life cycle of a wheat plant, i.e. the month of July, the terminal spikelet, stem elongation and booting phenological stages occur (Acevedo *et al.* 2002). Moderate water stress during these periods decreases cell growth and leaf area, reducing the photosynthesis per unit area (Acevedo *et al.* 2002). This reduction in photosynthesis impacts the active stages of plant growth, which hinders plant development; therefore, influencing the quality and quantity of the yield. More intense water deficits will cause partial stomata closure further reducing photosynthesis (Acevedo 1991).

Table 4.5: Pearson's correlation coefficients between various monthly rainfall characteristics and wheat yields over the 1994-2010 period. Values in bold indicate significance at the 10% level ($\rho<0.1$)

Rainfall Characteristics	Months					
	Apr	May	Jun	Jul	Aug	Sep
Rainfall	-0.174	**0.578**	0.035	0.298	-0.265	0.410
Wet Days	**-0.568**	**0.589**	0.178	0.363	-0.148	0.402
'Good' Rainfall	**0.512**	**0.428**	0.163	0.174	-0.216	0.182
% 'Good' Rainfall	**0.626**	0.084	0.281	0.019	-0.178	0.111
Dry Dekads	0.168	**-0.518**	-0.103	**-0.543**	0.157	-0.136

Figure 4.3 display the monthly rainfall (blue bars) from April to September for the six years selected above along with the average monthly rainfall (red dashed line). For both the years that experienced low yield, 2003 (Figure 4.3d) and 2004 (Figure 4.3e), significant below average May rainfall was recorded. However, during the years that obtained high yield, 1996 (Figure 4.3b) and 1999 (Figure 4.3c), each experienced below average May rainfall. The year of 2007 (Figure 4.3f) experienced the closest to average May rainfall and saw slightly below average yield. Given that discussion with farmers revealed the significance of sub-monthly rainfall characteristics, the next section examines correlations at this time scale.

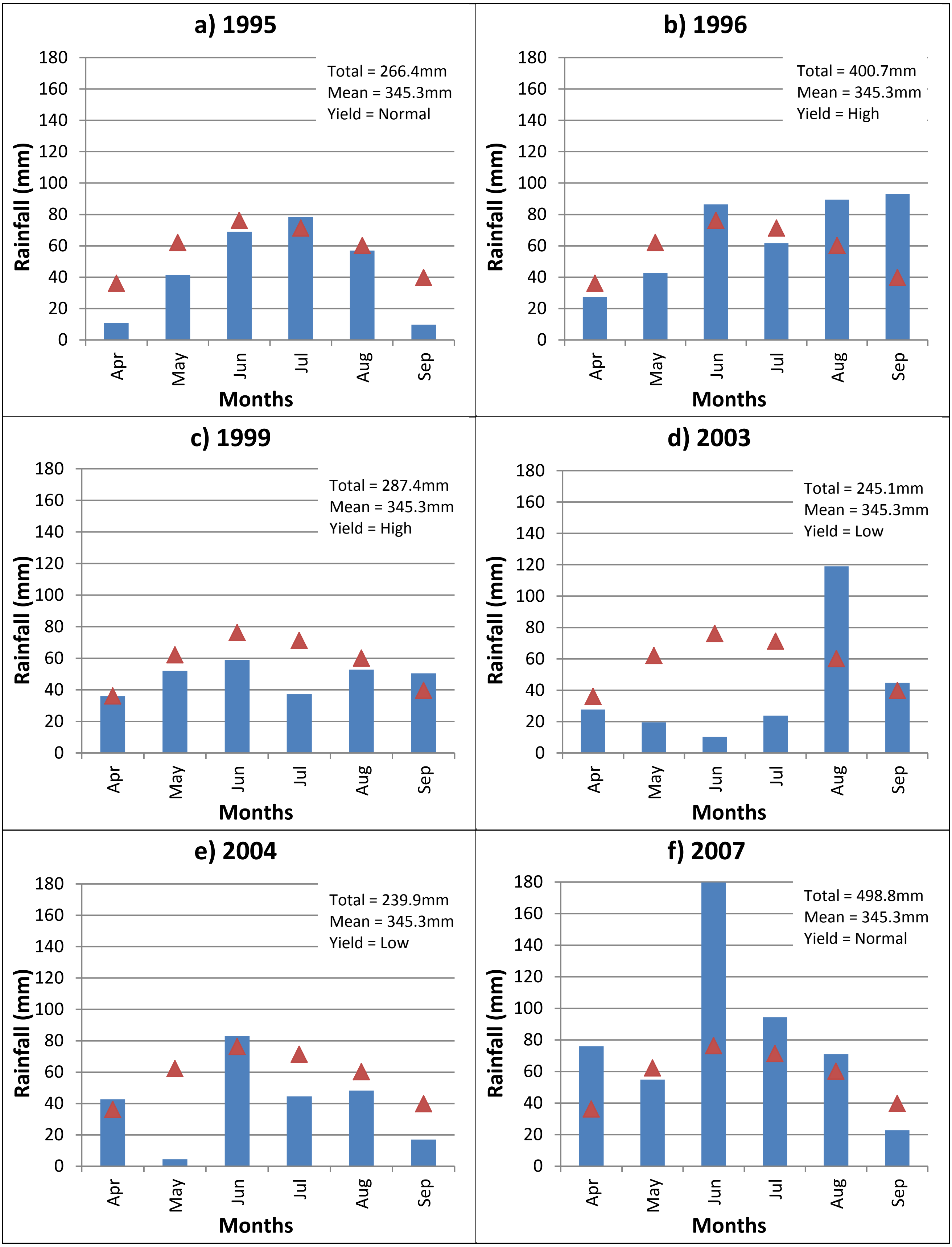

Figure 4.3 (a-f): Plots showing the monthly rainfall from April to September (blue bars) for six specific years, with the mean monthly rainfall from 1994 to 2010 (red markers) over the same period.

4.1.4 Dekadal rainfall and wheat thresholds

In order to further investigate the relationship between yield and the distribution of rainfall, three climatic thresholds, obtained through dialogue with wheat farmers from the Swartland (see Chapter 3), were analysed against the dekadal (10 day periods) rainfall record from 1994 to 2010. The three modified thresholds (see Chapter 3) used in the analysis were:

1. Minimum of 50mm over four dekads prior to planting (2nd dekad April – 2nd dekad May).
2. Minimum of 10mm per dekad over the growing season (3rd dekad May – 3rd dekad August).
3. Minimum of 14mm per dekad during September.

The wheat farmers expressed three threshold related scenarios they believed would affect the wheat yield of a particular year. If all three of the rainfall thresholds were met, farmers believed they were virtually guaranteed an above average (high) yield. Conversely, not meeting any of the thresholds 1, 2 or 3 was believed to lead to significant yield reduction. If threshold 1 was not met, but thresholds 2 and 3 were met, farmers felt that the wheat could still possibly recover to produce a high yield.

The graphs in Figure 4.4 display the rainfall in dekads and whether the rainfall met the three thresholds. The results are further summarised in Table 4.6, along with the recorded yield. The yield is given as the percentage deviation from the mean along with the category this falls into. The original tercile categories of low (one standard deviation below the mean), normal (within one standard deviation of mean) and high (one standard deviation above the mean) did not indicate the necessary level of detail as the normal category included a wide range of both positive and negative yield values. This was overcome by including two additional categories of “Normal-Low” (projection/actual yield between half a standard deviation and one standard deviation below normal), and conversely “Normal-High” (between half a standard deviation and one standard deviation above normal).

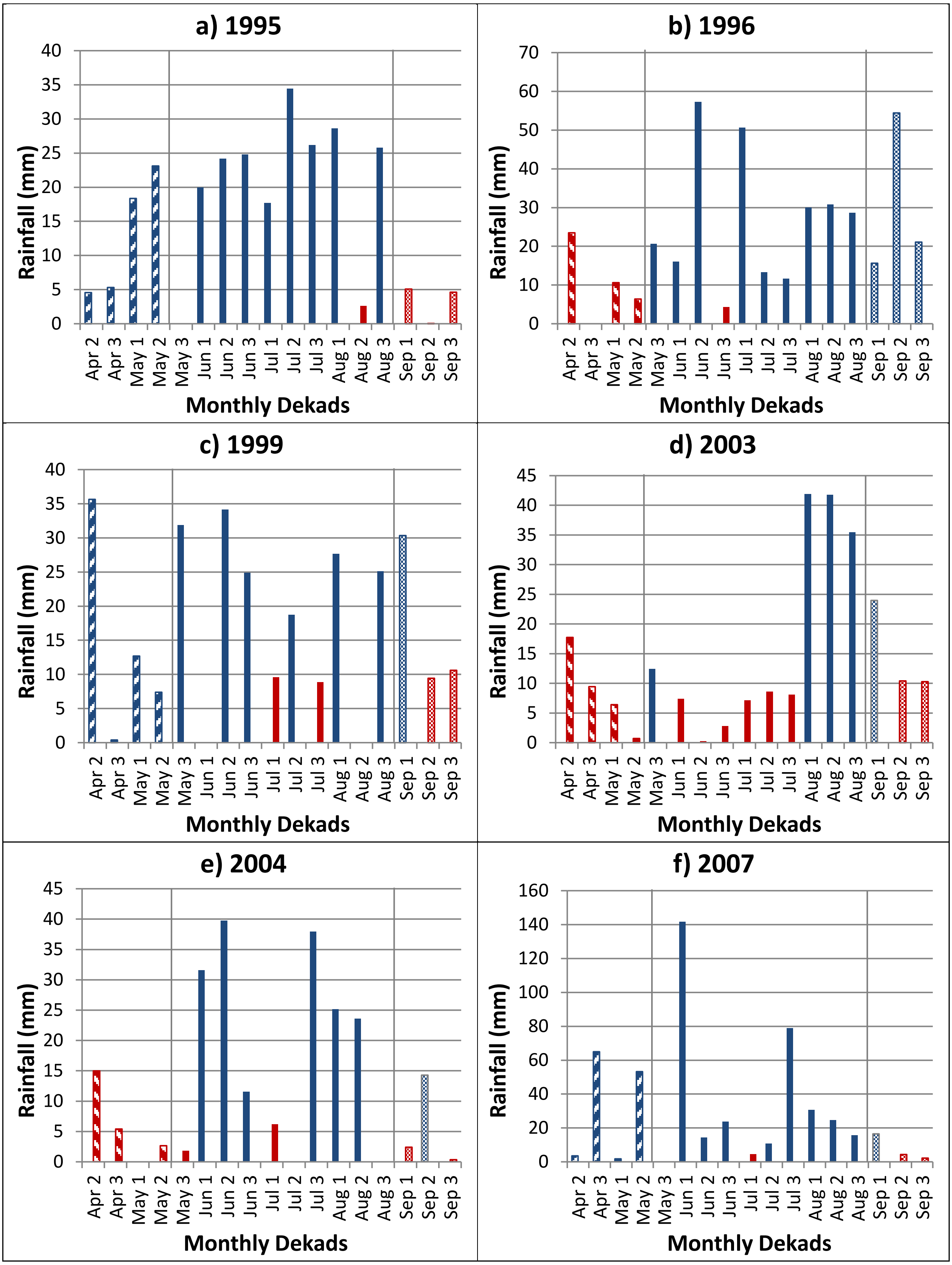

Figure 4.4 (a-f): Dekadal rainfall from April to September for selected years and an indication of whether this rainfall met the three rainfall thresholds specified by the wheat farmers. The first threshold (>50mm rainfall over six weeks before planting) is represented by the striped bars, with blue (red) bars indicating more (less) than 50mm over the period. The second critical threshold (>10mm of rain per dekad over the growing season) is represented by the solid bars, with dekads receiving more (less) than 10mm shown in blue (red). The third threshold (>14mm per dekad over September) is represented by the shaded bars, with dekads receiving more (less) than 14mm shown in blue (red).

From the examination of the results in Table 4.6 it is clear that the farmer-specified rainfall thresholds hold some value within the six sample years. Although perhaps slightly overestimated (with threshold 2 never being met during the six years), the thresholds do highlight significant periods, which influence the yield. In the case of 2003 (Figure 4.4d) and 2004 (Figure 4.4e), pre-seasonal rainfall was deficient (threshold 1), both incurred consecutive dry dekads in addition to dry Septembers, which resulted in low yields. In 1995 (Figure 4.4a) and 2007 (Figure 4.4f) only normal yields were achieved, despite both having sufficient pre-season rainfall (threshold 1) and few (two out of ten) dry dekads during the mid-season (threshold 2); however, they also both suffered from dry Septembers (threshold 3). During the year of 1996 (Figure 4.4b) a dry pre-season was overcome by excellent rainfall distribution with all but one of the next 13 dekads receiving more than 10mm resulting in a high yield. The wet pre-season in 1999 (Figure 4.4c) was coupled with an average growing season (however, the dry dekads alternated with wet dekads) and sufficient rainfall during the first dekad of September, followed by close to 10mm during the subsequent two dekads resulting in high yield.

Using the information given by the farmers with regards to the thresholds, along with the results from Table 4.6, a yield prediction system was developed based on whether the rainfall experienced during a growing season met the three thresholds. As the second and third thresholds were so seldom met the conditions were relaxed slightly. If six or more out of the ten dekad periods from the last dekad of May to the last dekad of August experienced above 10mm of rainfall it was deemed to have satisfied the second threshold. Similarly, if two or more out of the three September dekads received more than 14mm of rainfall this met the requirements of the third threshold. A year that failed to meet any of the thresholds was expected to experience low yield. Conversely, a year that satisfied all three rainfall thresholds was expected to experience high yield. Farmers believed a year that failed to meet threshold 1 could still possibly experience high yield, if thresholds 2 and 3 were met; therefore, years that experienced this situation were predicted to experience normal-high yield. If threshold 1 was met but both thresholds 2 and 3 were not, it would stand to reason that the lack of moisture throughout the growing season would result in low yield for that year. Years that experienced rainfall satisfying only one of thresholds 2 or 3 along with failing to meet threshold 1 would be expected to experience normal-low yield. Years that met threshold 1 along with either threshold 2 or 3, were expected to experience normal yield. The yield predicting algorithm is tabulated in Table 4.7.

Table 4.6: Conditional outcome of dekadal rainfall according to the three rainfall thresholds for six particular years and the wheat yield obtained.

Threshold reached	1995	1996	1999	2003	2004	2007
1	Yes	No	Yes	No	No	Yes
2	8/10	9/10	6/10	4/10	6/10	8/10
3	0/3	3/3	1/3	1/3	1/3	1/3
Yield (anomaly %)	-5.4 Normal	+37.2 High	+32.6 High	-61.4 Low	-46.7 Low	-4.0 Normal
Comment	Very Dry September	9 out of the last 9 dekads saw sufficient rainfall to make up for dry beginning	Dry dekads alternated with wet ones. Sept dry dekads were close to 10mm each	Dry prior to planting as well as 6 successive dry dekads from June	Very Dry May and 3 of the last 4 dekads dry	Four dekads received more than 50mm. Dry Sept

Table 4.7: Yield predicting algorithm. Showing possible threshold combinations and expected yields.

Threshold 1	X	✓	X	X	✓	✓	X	✓
Threshold 2	X	X	✓	X	X	✓	✓	✓
Threshold 3	X	X	X	✓	✓	X	✓	✓
Predicted Yield	Low		Normal-Low		Normal		Normal-High	High

The yield predicting algorithm was tested on the remaining eleven years. Taking into account all the threshold requirements, each year was assessed and a yield was predicted as seen in Table 4.8. Out of the eleven years in Table 4.8, ten of the predicted yields were correct or marginally correct with only the year 2000 proving incorrect. Figure 4.5 (a-f) contains the dekadal rainfall distribution of the incorrect year 2000 and five years, which were marginally correct to examine the outcomes of the predicted yield. In 2000 the threshold data suggested a normal-low yield with only the third threshold being met; however, a normal-high yield occurred. The year 2000 (Figure 4.5b) experienced a very dry pre-season and a mid-season that failed to meet the second threshold, with only five out of the ten dekads receiving more than 10mm. This 'dry' mid-season according to the threshold seems to have been overcome by the alternating of the dry dekads with the wet dekads, in addition none of the five wet dekads received less than 18mm of rainfall and the second dekad of June received over 60mm of rainfall. A wet September with two out of three dekads receiving more than 14mm helped to achieve a normal-high yield.

Table 4.8: The threshold achieved by eleven specific years with predicted and actual yields

Thresholds	1994		1997		1998		2000		2001		2002	
1	N	x	N	x	Y	✓	N	x	Y	✓	N	x
2	6/10	✓	8/10	✓	6/10	✓	5/10	x	7/10	✓	10/10	✓
3	2/3	✓	0/3	x	0/3	x	2/3	✓	1/3	x	2/3	✓
Expected Yield	Normal-High		Normal-Low		Normal		Normal-Low		Normal		Normal-High	
Actual Yield	-0.9% Normal		-27.6% Low		-8.3% Normal		+13.7% Normal-High		+12.0% Normal		+16.3% Normal-High	

Thresholds	2005		2006		2008		2009		2010	
1	Y	✓	Y	✓	N	x	Y	✓	Y	✓
2	8/10	✓	8/10	✓	8/10	✓	8/10	✓	6/10	✓
3	1/3	x	1/3	x	3/3	✓	1/3	x	0/3	x
Expected Yield	Normal		Normal		Normal-High		Normal		Normal	
Actual Yield	-13.3% Normal-Low		+17.2% Normal-High		+1.4% Normal		+16.2% Normal-High		+21.1% Normal-High	

In 2001 a normal yield was predicted with only the third threshold not being met; however, this year actually saw normal-high yield. From Figure 4.5c, 2001 received very high rainfall during the first and second dekads of June (>160mm), coupled with the three consecutive wet dekads (>30mm each) from the second dekad in August to the first dekad of September. These conditions may have resulted in adequate soil moisture to overcome the two dry dekads at the end of the season for the crop to receive normal-high yield. A 'normal' yield was predicted for 2005 as it received adequate pre-season and mid-season rainfall. A dry first dekad of September followed by very low rainfall during the second dekad of September (Figure 4.5d) seems to have been enough to cause 2005 to have received normal-low yield. According to the thresholds the year of 2009 (Figure 4.5f) received exactly the same rainfall as 2005, each receiving sufficient pre-season rainfall, only two dry dekads during the mid-season and one wet dekad during September; however, 2005 experienced normal-low yield whilst 2009 received normal-high yield. Three of the last four dekads in 2009 were dry and yet the wheat crop produced that year still managed to be 16% above the mean yield. The marginally correct result in 2008 (Figure 4.5e) seems hard to rationalize, as although a dry pre-season was experienced the mid and late seasonal periods received ample rainfall with only two out of the thirteen dekads not receiving the required amounts. This led to a normal-high predicted yield; however, this year only received normal yield.

The threshold analysis indicated the wheat crop initially requires adequate soil moisture for germination and the initial stages of crop development known as emergence (threshold 1).

Threshold 2 indicated regular rainfall is needed during growth stages one and two, which include the phenological stages; tillering, floral initiation, double ridge, terminal spikelet, first node, boot and spike emergence. From threshold 3, adequate and distributed rainfall during growth stage three (anthesis and maturity), was seen to be a critical factor in determining the wheat yield.

The results of this experimental analysis are encouraging; however, the handful of years that showed contradictory results highlights the need for further study. It is important to keep in mind that rainfall is not the only determining factor on wheat yields and that additional environmental stresses exist, which can severely impact the yield of the wheat crop. Rainfall has been shown to impact wheat yield on various time scales. It is possible that the distribution of the winter rainfall is a greater determinant of wheat yield than the total rainfall received throughout the growing season in the Swartland. However, this has not been specifically addressed in this study. The results do indicate that there could be specific periods during the wheat growing season for which rainfall can impact the wheat yield.

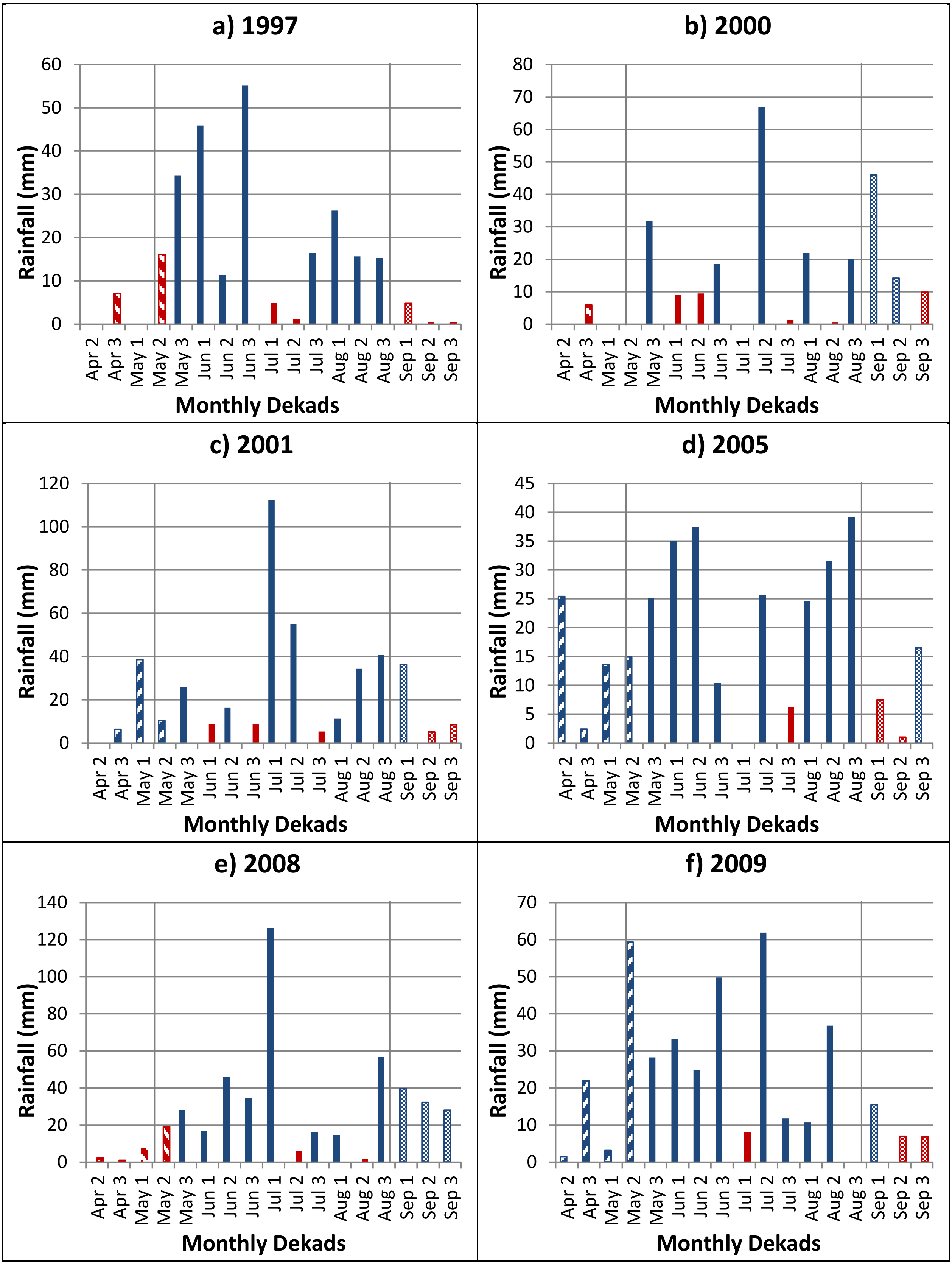

Figure 4.5 (a-f): Dekadal rainfall from April to September for selected years and an indication of whether this rainfall met the three rainfall thresholds specified by the wheat farmers. The first threshold (>50mm rainfall over six weeks before planting) is represented by the striped bars, with blue (red) bars indicating more (less) than 50mm over the period. The second critical threshold (>10mm of rain per dekad over the growing season) is represented by the solid bars, with dekads receiving more (less) than 10mm shown in blue (red). The third threshold (>14mm per dekad over September) is represented by the shaded bars, with dekads receiving more (less) than 14mm shown in blue (red).

4.2 Association of climate indices with wheat yield

4.2.1 Correlation analysis

This section of the analysis attempts to determine whether any links exist between large-three scale teleconnections (El Niño-Southern Oscillation [ENSO], South Atlantic sea surface temperatures [SSTs] and the Antarctic Oscillation [AAO]) and the wheat yield observed in the Swartland. The eight climate indices used in this analysis are; Antarctic Oscillation Index (AAO), Southern Annual Mode Index (SAM), Nino3.4 Index (Nino3.4), Ocean Nino Index (ONI), Southern Oscillation Index (SOI), South Atlantic Dipole Index (SADI), South Western Atlantic SST Index (SWAI) and the South Central Atlantic SST Index (SCAI), see Chapter 3 for definitions.

Figure 4.6 displays the correlations between the wheat yield and the AAO indices (Figure 4.6a), ENSO indices (Figure 4.6b) and South Atlantic SST indices (Figure 4.6c). The AAO and SAM indices show a similar correlation pattern with wheat yield throughout the year; however, only three correlations are significant at the 10% significance level ($\rho<0.1$). Both AAO and SAM indices during the OND months show positive significant correlations with wheat yield ($r=0.424$, $\rho<0.1$ and $r=0.480$, $\rho<0.1$ respectively), whilst SAM JAS show a significant negative correlation
($r= -0.461$, $\rho<0.1$). Previous studies have shown a negative (positive) phase of AAO/SAM to be associated with wetter (drier) winters in South Africa (Reason *et al.* 2002; Reason & Rouault 2005). This could possibly explain the negative correlation for the JAS period, months during which significant phenological phases of the wheat crop occur (stem elongation, boot, spike emergence, anthesis and maturity). Water stress during these phenological phases could negatively affect the wheat yield (Acevedo *et al.* 2002). After the wheat crop has reached maturity (typically end of September, early October) the crop is left in the field to dry before harvesting in November or early December. Rainfall during this drying period can considerably reduce the yield of the crop as the damp conditions cause disease and preharvest sprouting (Agricultural Research Council-Small Grain Institute [ARC-SGI] 2013). The positive correlation of OND AAO and yield may be a reference to the importance of a dry preharvest period.

The ENSO indices display relatively consistent correlations throughout the year (Figure 4.6b). The ONI and Nino3.4 indices show negative correlation with wheat yield although only the JFM, JJA and JAS periods of the ONI Index show significant ($\rho<0.1$) correlation with the wheat yield ($r= -0.423$, $r= -0.430$ and $r= -0.426$ respectively). The SOI Index shows positive correlations with the yield throughout the year with significant correlations during the FMA ($r=0.434$, $\rho<0.1$), MAM ($r=0.556$, $\rho<0.05$) and AMJ ($r=0.696$, $\rho<0.0025$). Consistently positive (negative) Nino3.4 Index and ONI (SOI) months indicate El Niño (La Niña) episodes. Previous studies have shown positive (negative) anomalies in winter rainfall (May, June and July) to occur during El Niño (La Niña) events (Philippon *et al.* 2011). These correlations are rather surprising as they suggest years of above normal yield are associated with years during which negative Nino3.4 and ONI and positive SOI occur, i.e. years that are supposedly La Niña and drier. This relationship will be further discussed in Chapter 5.

Two of the three South Atlantic SST indices show significant correlations with wheat yield at the seasonal scale (Figure 4.6c). The SCAI displays significant positive correlations at the beginning of the year during the JFM ($r=0.542$, $\rho<0.05$) and FMA ($r=0.460$, $\rho<0.1$) periods. This result suggests that during the first four months of the year anomalously warmer SSTs over the central region of the South Atlantic Ocean (36°-44°S, 0°E-18°W) coincide with years of above average wheat yield in the Swartland region. As these months occur before the wheat growing season, the SST anomalies will not directly affect the mid-latitude cyclones, which bring the winter rainfall. The influence of the various climate indices on each other was assessed through correlation with the SCAI showing strong significant correlation (values ranged between -0.563 and -0.705 with ONI, all of which were significant at the 1% significance level) with the ENSO indices during the summer months (November to April). This strong influence ENSO has on the central South Atlantic SSTs during the summer months, account for the significant positive correlation during the beginning months of the year between SCAI and yield. The SWAI (29°-45°S, 48°-64°W) shows a negative correlation ($r= -0.493$, $\rho<0.05$) during the MJJ period with wheat yield. This result is not consistent with previous studies (Reason *et al.* 2002; Reason & Jagadheesha 2005), which suggest anomalously warmer SSTs in the western South Atlantic are associated with wetter winters in the South Western Cape (SWC) region of South Africa. The SADI does not display any significant correlations with wheat yield.

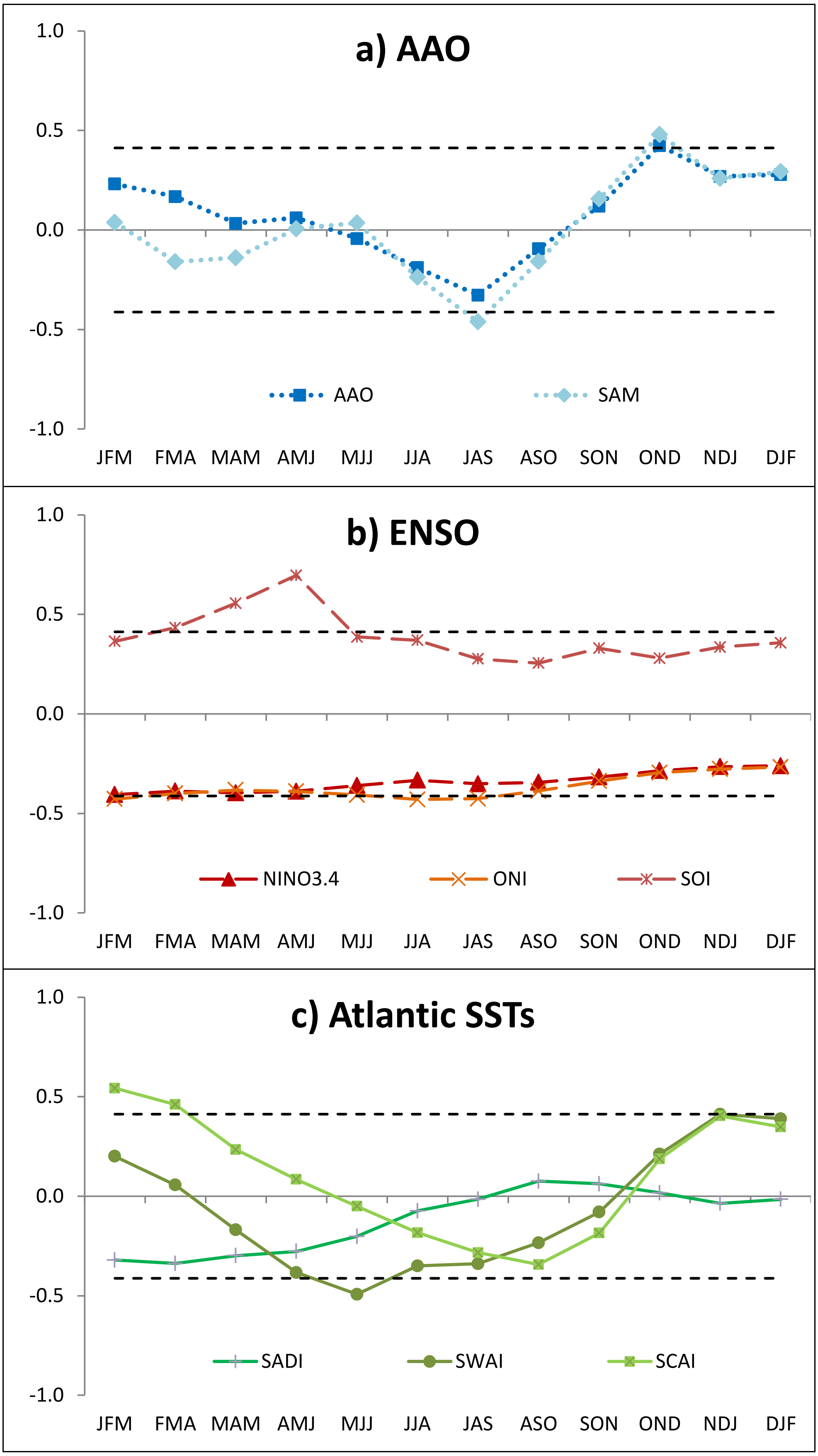

Figure 4.6 (a-c): Pearson's correlation between wheat yield and **a)** AAO, **b)** ENSO and **c)** South Atlantic SST indices over the 1994-2010 period. Dashed lines indicate significance at ρ= 0.1. and ρ= -0.1

4.2.2 Large-scale surface and atmospheric circulation pattern analysis

To expand the interpretation of the correlations found between the climate indices and yield, composite climatology and anomaly plots were created to examine the large-scale surface and atmospheric circulation patterns associated with years of extreme yields. The climatology during winter (April to September) for various climatic variables are examined to give context to the anomalous conditions associated with years, which experienced anomalously high and low yield in the Swartland region. To ease comparisons the climatology and anomaly plots are displayed by climatic variable.

The surface pressure, SST and surface wind climatology plots between the equator and 70°S (50°S for SSTs) over the winter period from 1981 to 2010 can be seen in Figures 4.7a, 4.8a and 4.9a respectively. The subtropical high pressure belt caused by the subsiding air of the Hadley cell circulation is centred around 30°S across the Southern Hemisphere, commonly referred to as horse latitudes. Three high pressure cells are clearly visible over the southern extent of the Pacific (South Pacific High), Atlantic (South Atlantic High) and Indian (South Indian High) oceans. Moving poleward the surface pressure quickly decreases to below 990mb around 70°S. This strong change in the pressure gradient between 40°S and 60°S results in the band of strong westerly wind across the Southern Hemisphere in this region. The three high pressure cells over the Pacific, Atlantic and Indian Oceans cause the anticyclonic surface circulation over these regions. This anticyclonic surface circulation in turn influences the SST patterns in the Southern Hemisphere ocean gyres. The south-south easterly (north-north westerly) winds caused by the anticyclonic flow around the subtropical high pressure cells result in cooler (warmer) SSTs to propagate to lower (higher) latitudes along the southern African and South American western (eastern) coast lines.

Figures 4.7b, 4.8b and 4.9b display anomaly plots showing the difference between the climatology and the mean (climatology subtracted from mean) surface pressure, SSTs and surface wind respectively, for three years that experienced the highest yield (1996, 1999 and 2010) between 1994 and 2010. The South Pacific High pressure cell intensifies and expands westward during years of surplus yield, whilst surface pressure centred around 60°S, 100°W decrease strongly. These changes in pressure strengthen the already existing pressure gradient force intensifying the westerly wind between 40°S and 60°S in the south Pacific. The expansion and strengthening of the surface circulation of the anticyclonic South Pacific High pressure cell amplifies the south easterly winds that transports surface water away from the South American coast, inducing upwelling of cold water to the surface. This cooler water is then transported along the surface in a north-westerly direction towards the equator. If the intensifying of the upwelling system in the eastern Pacific and the associated anomalously cooler SSTs along the equator persist it is known as a La Niña event. Examining the phase of ENSO during the three years of anomalously high yield reveals all three are somewhat effected by La Niña events (Figure 4.10). During 1996 a La Niña event ended as the winter season started with ONI values remaining negative throughout. A strong La Niña event occurred during 1999 and 2010 saw an El Niño event end and a La Niña event start during the winter season.

A weak low pressure anomaly centred around 45°S-5°W in the South Atlantic region is evident, whilst a weak high pressure anomaly is observed off the east coast of South America. These opposing anomalies increase the pressure gradient force in the region strengthening the westerlies between the two pressure anomalies. The storm tracks shift northwards in the south Atlantic bringing more rain to the Western Cape (Reason *et al.* 2002). The setup of the pressure anomalies cause the southerly winds to blow across the area where the South Atlantic high pressure is typically located (centre at 30°S), which corresponds with anomalously lower SSTs in this region. Warmer SSTs are observed over the northern extent of the South Atlantic.

Figures 4.7c, 4.8c and 4.9c show the same as Figures 4.7b, 4.8b and 4.9b but for three years of anomalously low wheat yield. Over the south Pacific a reversal of the signs of the anomalies that were observed during years of surplus is observed with the South Pacific high pressure weakening, whilst the pressures over 40°-60°S increase. This results in a weakening of the surface circulation over the northern extent of the south Pacific, resulting in less upwelling; therefore, causing SSTs to increase off the west coast of South America and over the equatorial Pacific. These persistent warmer SST anomalies are associated with El Niño events. Examining the state of ENSO during the three years of low yield, Figure 4.10 shows 1997 experienced an El Niño event during the winter season. An El Niño event ended at the beginning of 2003, whilst 2004 saw the beginning of an El Niño event during the latter half of the year.

During years of deficit yield the South Atlantic remains in a relatively normal state in terms of surface pressure with the exception of the strengthening of the South Atlantic and south Indian high pressure cell and its expansion south of South Africa. This may be associated with storm tracks moving further to the south, away from the Western Cape. A slight warming of the SST in the central South Atlantic is observed, whilst cooler SSTs are observed over the northern extent of the South Atlantic.

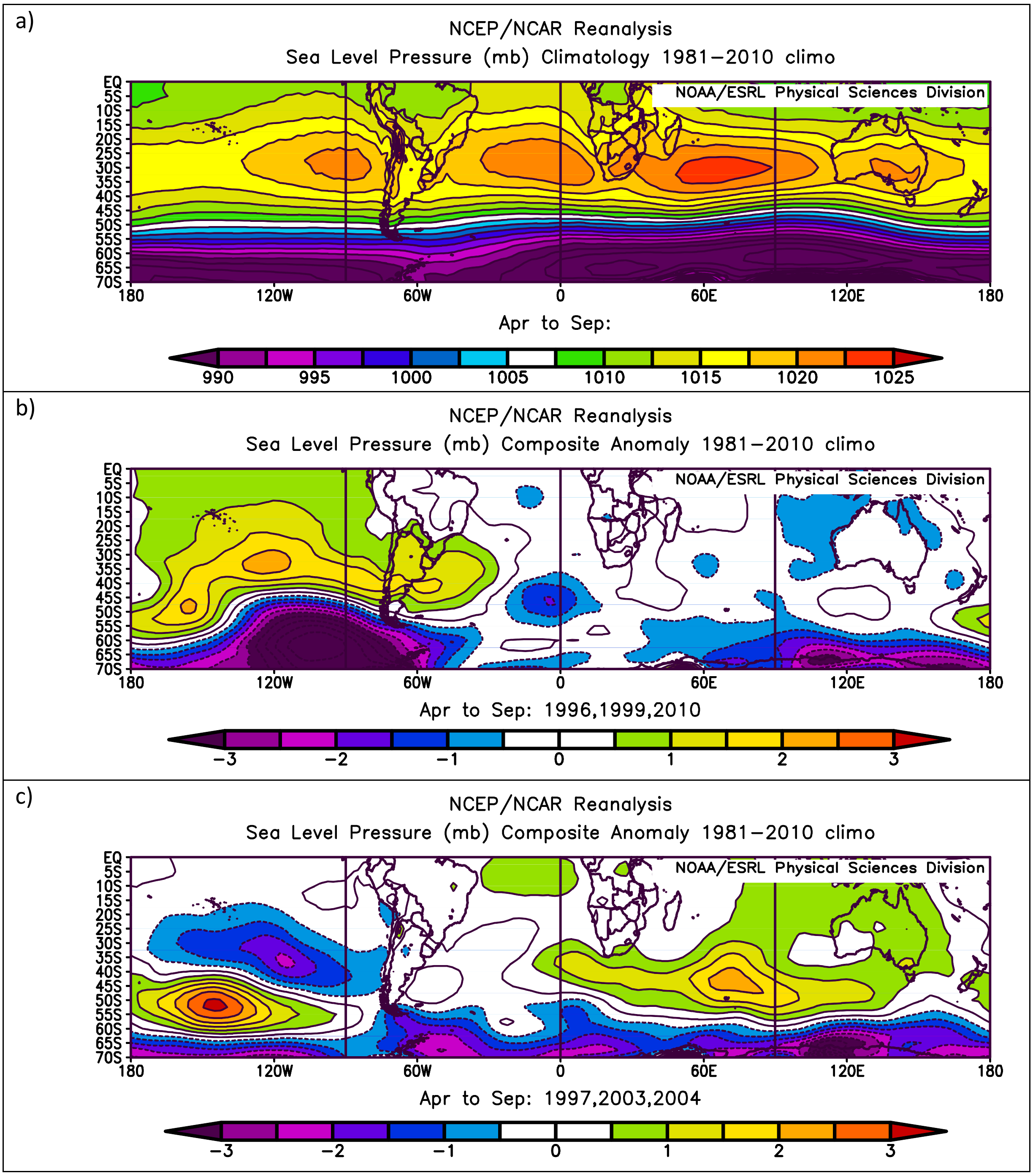

Figure 4.7 (a-c): Surface pressure composite plots over the winter period (Apr-Sept) showing **a)** the climatology from 1981 to 2010, **b)** pressure difference for three years of anomalously high yield and **c)** pressure difference for three years of anomalously low yield.

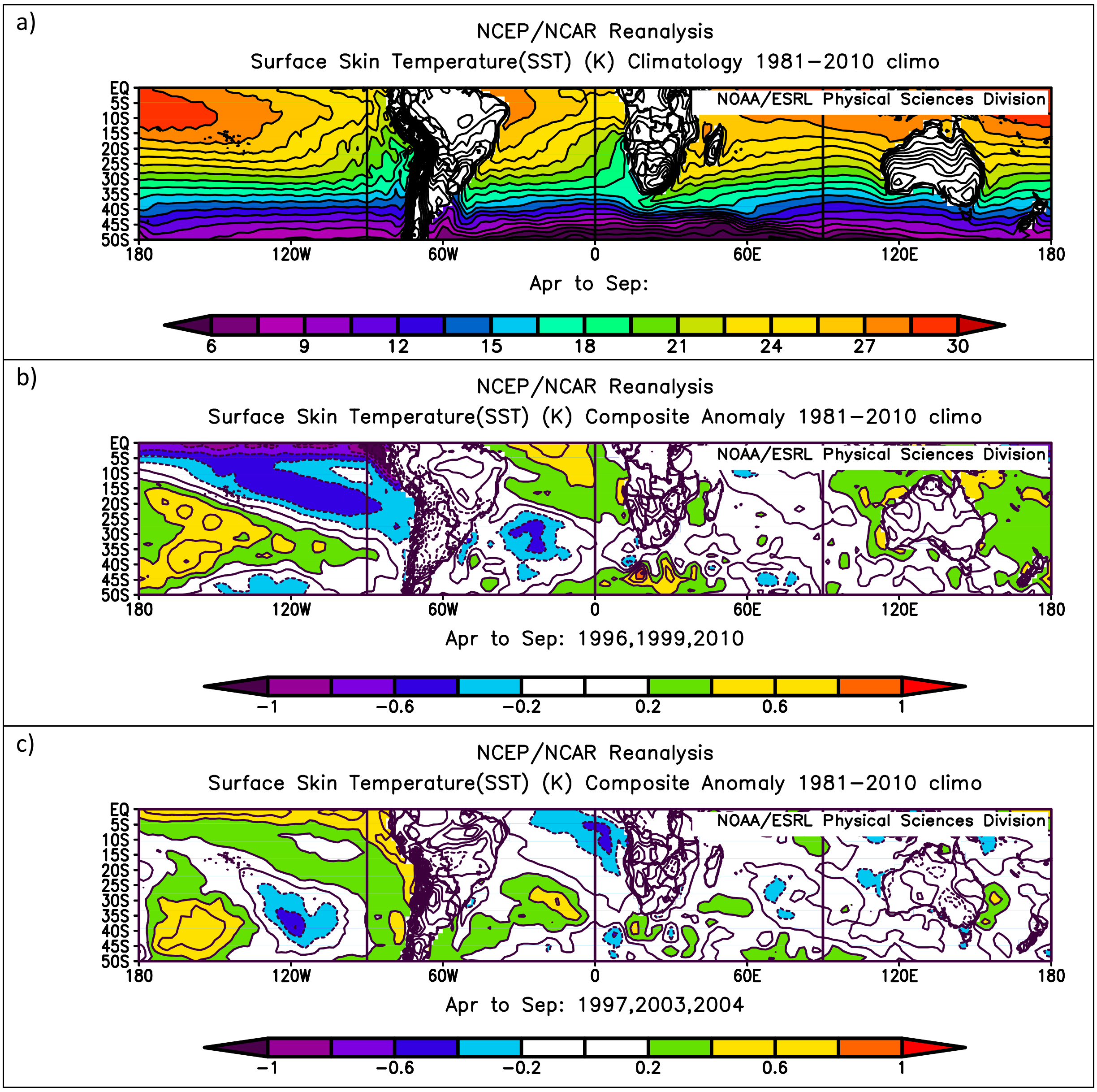

Figure 4.8 (a-c): Sea surface temperature (SST) composite plots over the winter period (Apr-Sept) showing **a)** the climatology from 1981 to 2010, **b)** SST difference for three years of anomalously high yield and **c)** SST difference for three years of anomalously low yield**.**

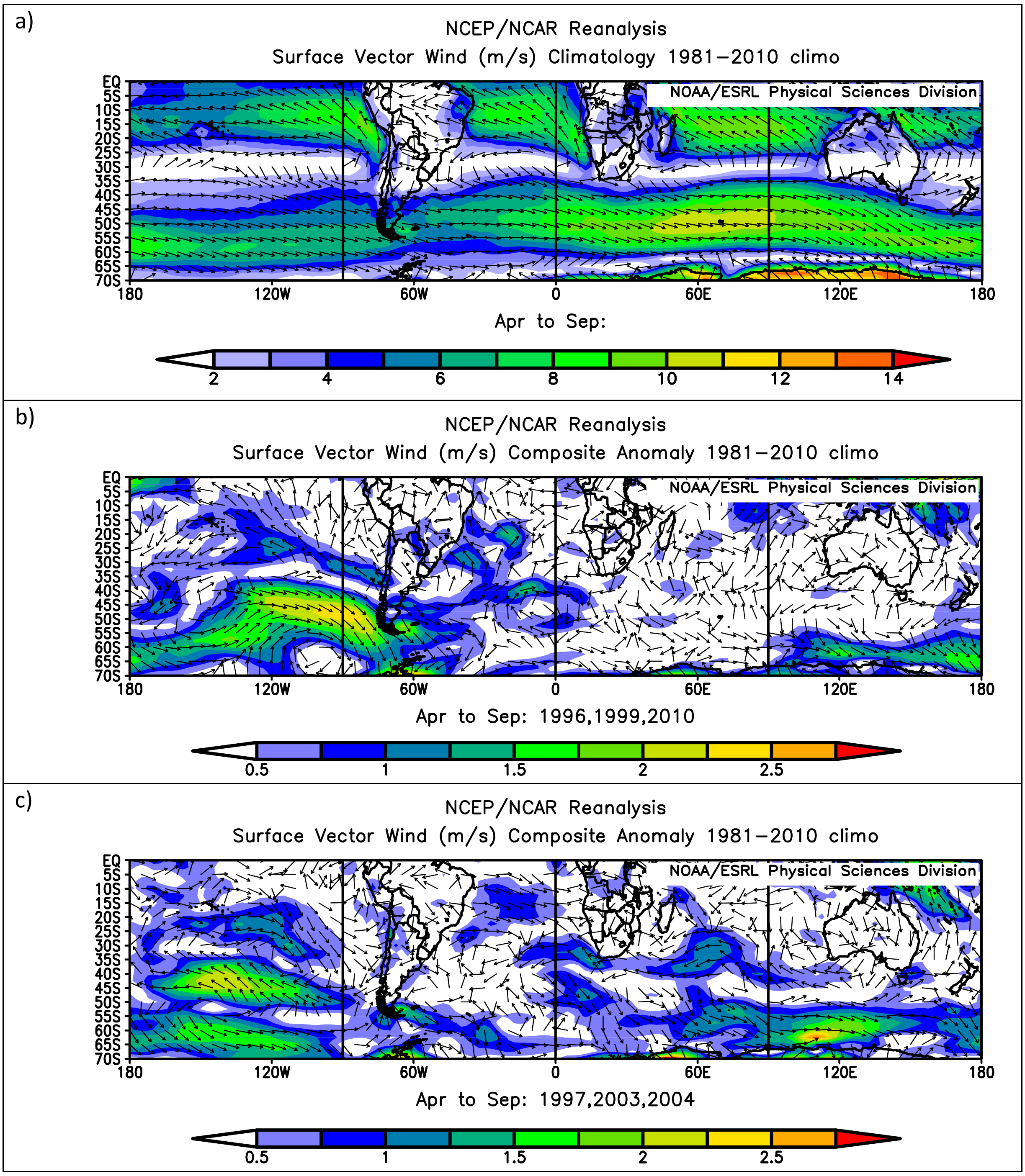

Figure 4.9 (a-c): Surface wind composite plots over the winter period (Apr-Sept) showing **a)** the climatology from 1981 to 2010, **b)** wind vector difference in the wind direction and strength for three years of anomalously high yield and **c)** wind vector difference in the wind direction and strength for three years of anomalously low yield.

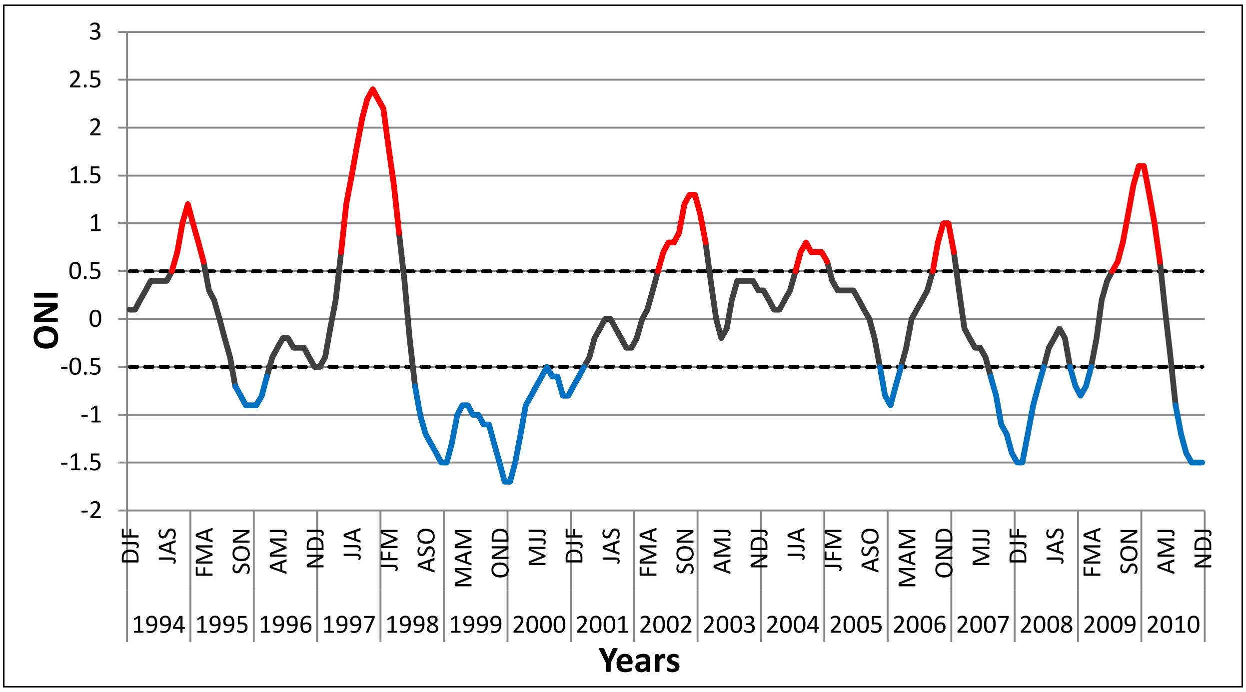

Figure 4.10: Oceanic Nino Index from 1994 to 2010. The red, grey and blue sections of the time series indicate El Niño, ENSO neutral and La Niña events respectively.

The physical robustness of these observed large-scale dynamics during years of wheat surplus and deficit were tested by using a range of the years, which corresponded to the highest and lowest yield, to create composite anomaly plots for a number of atmospheric variables (only surface pressure shown). Figure 4.11 (a-c) displays the surface pressure composite anomaly plots (surplus-deficit) for averages of the two, three and four highest and lowest wheat yield years respectively. The anomalously low pressure pattern across the southern extent of the Pacific, Atlantic and Indian Oceans are observed throughout. This pressure pattern shows resemblance of a wavenumber 3 type pattern; however, further investigation is needed to confirm this (which falls outside the scope of this study). The anomalously low pressures in the mid-latitudes and the anomalously high pressures in the higher latitudes (close to Antarctica) seen in Figures 11 indicate a negative (positive) AAO phase is associated with years of wheat yield surplus (deficit). During a negative AAO phase a weakening of the zonal (westerly) winds occurs and a northward shift in the mid-latitude storms tracks is observed. A positive AAO phase indicates the occurrence of a strengthening circumpolar vortex and westerly winds that shifts the storm tracks southward.

Figure 4.12 (a and b) displays the surface pressure composite anomaly (surplus-deficit) for the early (April to June) and late (July to September) seasonal periods respectively. Anomalously lower (higher) surface pressures can be observed over the central and eastern South Atlantic during both the early and late seasonal periods with higher (lower) pressures observed over the western part of the South Atlantic during years of surplus (deficit). There is a general increase in surface pressure over the higher latitudes between the early and late seasons, which shift the anomalously lower pressures equatorward in the Pacific and Indian Oceans during years of surplus. The early and late seasonal anomaly surface pressure patterns are relatively similar to one another, especially over the South Atlantic close to South Africa where they remain low, which enforces the idea that these large-scale atmospheric circulations affect the wheat growing region of the Swartland throughout the growing season by altering the position of the winter storms, which bring rain to the Western Cape.

The results in this section clearly support the correlations of the climate indices and wheat yield.

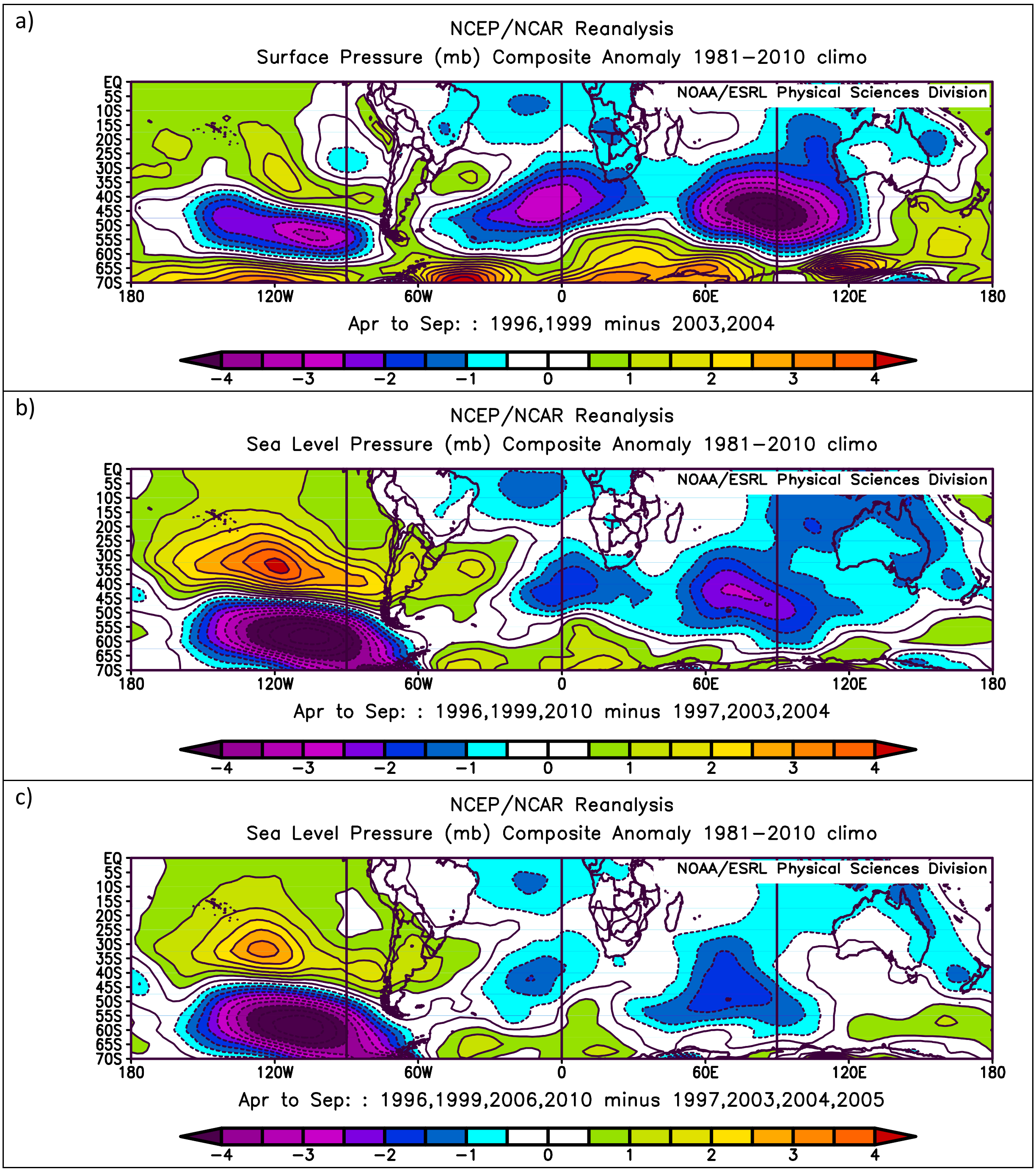

Figure 4.11 (a-c): Surface pressure composite anomaly plots over Apr-Sept from 1994-2010 for years of anomalously high yield subtracted from years of anomalously low yield. Plots use **a)** two, **b)** three and **c)** four years of highest and lowest yields. See yearly annotations on figures.

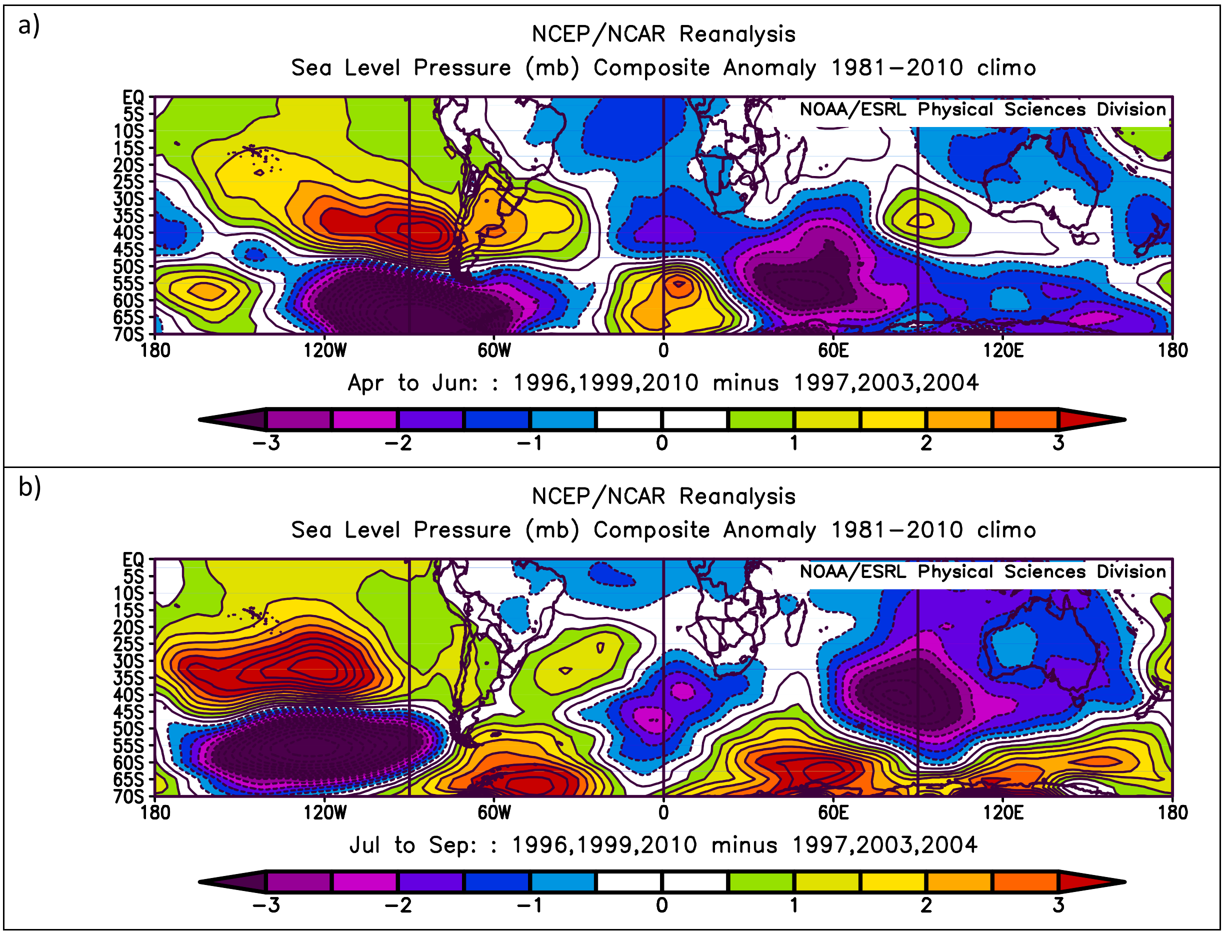

Figure 4.12 (a-b): Surface pressure composite anomaly plots during the **a**) early (Apr-Jun) and **b)** late (Jul-Sept) seasonal periods for three years of anomalously high yield subtracted from three years of anomalously high yield. See yearly annotations on figures.

4.3 Association of rainfall characteristics with climate indices

This section attempts to determine whether any connections exist between the climate indices and rainfall characteristics within the three areas of the Swartland region over the 1980-2012 period. Eight climate indices representing three teleconnections (ENSO, South Atlantic SSTs and AAO) were correlated against six rainfall characteristic indices. Both the climate and rainfall indices were in overlapping trimonthly format. Selected portions of the correlation tables are shown below, highlighting the majority of the significant relationships relevant for wheat production. All additional results can be seen in Appendix A.

4.3.1 El Niño -Southern Oscillation

4.3.1.1 With total seasonal rainfall

Three climate indices were used to represent ENSO – namely, Nino3.4 Index, Ocean Nino Index (ONI) and the Southern Oscillation Index (SOI) (see Chapter 3 for definitions). The three ENSO indices were correlated with *rainfall*, with Table 4.9 displaying the correlation coefficients between the ENSO indices and the total seasonal (over lapping three month periods) *rainfall* for each of the three areas. In Table 4.9 the red (blue) highlighted coefficients indicate significant negative (positive) correlations with darker shades representing greater significance.

Comparing the correlation coefficients within the three areas, the dissimilarity of Area 1 (northern extent) from that of Areas 2 (eastern extent, inland) and 3 (western extent, coastal) is prominent. A clear positive-negative correlation pattern is evident between the ENSO indices and the seasonal *rainfall* in Areas 2 and 3. The Nino3.4 Index and the ONI show positive correlations with *rainfall* during the earlier seasonal periods, strengthening as they move towards synchronous periods (i.e. AMJ Nino3.4 correlated with AMJ *rainfall*). The later seasonal periods of *rainfall* display negative correlation with the Nino3.4 Index and ONI with correlations peaking during the first few seasonal periods of the year for the ENSO indices. As expected the opposite correlation pattern is observed between the SOI and *rainfall* from Areas 2 and 3. Area 3 displays more significant correlations between early seasonal *rainfall* periods and the ENSO indices than Area 2, with the AMJ *rainfall* period showing the strongest correlations. Area 2, however, displays stronger correlations between the three ENSO indices and *rainfall* during the latter seasonal periods. These results suggest ENSO to have; limited association with rainfall in the drier northerly area; a greater association with late winter rainfall in the inland Swartland region; and a greater influence on early winter rainfall along the coastal area.

Table 4.9: Pearson's correlation coefficients obtained from comparing three ENSO indices with rainfall over the 1980-2012 period from the three study areas. Highlighted coefficients are significant at the 10% significance level with darker shadings indicating greater significance (see key).

ENSO		Area 1 Rainfall						Area 2 Rainfall						Area 3 Rainfall					
		MAM	AMJ	MJJ	JJA	JAS	ASO	MAM	AMJ	MJJ	JJA	JAS	ASO	MAM	AMJ	MJJ	JJA	JAS	ASO
NINO3.4	JFM	-0.134	0.075	0.085	0.102	-0.113	-0.306	0.073	0.212	0.058	-0.172	-0.359	-0.257	0.228	0.324	0.217	-0.055	-0.336	-0.274
	FMA	0.133	0.097	-0.071	-0.115	-0.195	-0.298	0.102	0.252	0.098	-0.184	-0.382	-0.301	0.269	0.399	0.287	-0.036	-0.352	-0.310
	MAM	0.066	-0.135	-0.246	-0.237	-0.100	0.023	0.098	0.309	0.181	-0.132	-0.387	-0.381	0.273	0.495	0.403	0.046	-0.355	-0.374
	AMJ		-0.178	-0.181	-0.296	-0.053	0.026		0.319	0.237	-0.004	-0.329	-0.397		0.515	0.463	0.189	-0.283	-0.350
	MJJ			-0.009	-0.223	-0.058	-0.032			0.209	0.120	-0.175	-0.270			0.403	0.299	-0.117	-0.186
	JJA				-0.184	-0.124	-0.230				0.194	-0.052	-0.134				0.355	0.014	-0.038
	JAS					-0.169	-0.267					-0.017	-0.072					0.057	0.027
	ASO						-0.168						-0.079						0.010
ONI	JFM	-0.108	-0.121	0.034	0.234	0.282	0.181	0.089	0.236	0.059	-0.166	-0.381	-0.270	0.237	0.348	0.227	-0.037	-0.347	-0.279
	FMA	-0.065	-0.143	0.017	0.147	0.241	0.159	0.104	0.271	0.092	-0.172	-0.408	-0.319	0.258	0.416	0.296	-0.006	-0.365	-0.319
	MAM	0.022	-0.175	-0.167	-0.068	0.148	0.152	0.083	0.307	0.149	-0.142	-0.427	-0.386	0.241	0.494	0.393	0.063	-0.380	-0.372
	AMJ		-0.216	-0.145	-0.101	0.189	0.204		0.310	0.200	-0.049	-0.378	-0.393		0.515	0.452	0.166	-0.328	-0.353
	MJJ			-0.192	-0.135	0.154	0.235			0.189	0.052	-0.259	-0.303			0.417	0.253	-0.202	-0.231
	JJA				-0.074	0.232	0.293				0.117	-0.135	-0.177				0.299	-0.066	-0.085
	JAS					0.166	0.269					-0.061	-0.095					0.017	0.002
	ASO						0.260						-0.069						0.020
SOI	JFM	0.083	0.120	-0.046	-0.251	-0.354	-0.193	-0.136	-0.258	-0.092	0.127	0.296	0.267	-0.306	-0.388	-0.266	0.023	0.285	0.278
	FMA	0.123	0.181	0.007	-0.235	-0.373	-0.232	-0.049	-0.241	-0.076	0.072	0.265	0.250	-0.259	-0.418	-0.302	-0.077	0.244	0.269
	MAM	0.146	0.270	0.109	-0.153	-0.376	-0.283	0.121	-0.175	-0.171	-0.070	0.170	0.201	-0.095	-0.379	-0.400	-0.229	0.143	0.210
	AMJ		0.342	0.219	0.012	-0.319	-0.289		-0.124	-0.070	-0.067	0.195	0.188		-0.318	-0.301	-0.267	0.122	0.152
	MJJ			0.262	0.168	-0.208	-0.224			-0.107	-0.100	0.131	0.165			-0.259	-0.255	0.066	0.101
	JJA				0.253	-0.104	-0.139				-0.038	0.204	0.226				-0.262	0.095	0.127
	JAS					-0.048	-0.094					0.147	0.211					0.045	0.116
	ASO						-0.089						0.206						0.134

Table 4.9 Key

ρ value	Value		Significance
	Negative	Positive	
0.1	-0.2913	0.2913	10.00%
0.05	-0.3440	0.3440	5.00%
0.02	-0.4032	0.4032	2.00%
0.01	-0.4421	0.4421	1.00%
0.005	-0.4770	0.4770	0.50%
0.002	-0.5184	0.5184	0.20%

Inspecting the significant positive correlations between ONI and Area 3 *rainfall* during the AMJ period, Figure 4.13 plots the standardized detrended MAM ONI and AMJ *rainfall* series from 1980 to 2012 against each other. The blue circles, red triangles and black crosses, seen in Figure 4.13 indicate La Niña, El Niño and ENSO-neutral years respectively (see Chapter 3 for definitions). Although anomalously high and low rainfall is observed during ENSO-neutral years the El Niño and La Niña years show more constrained distributions. From Figure 4.13, all six of the MAM ONI periods to have occurred during a La Niña event coincided with years that received below average AMJ *rainfall*, whilst four out of the five MAM ONI periods to have occurred during El Niño events received above normal AMJ *rainfall*. The wettest and driest AMJ occurred during years that were ENSO-neutral. Similar results were observed when examining the AMJ ONI-AMJ *rainfall* for Area 3, with all six La Niña and four of the seven El Niño AMJ ONI periods experienced below and above average *rainfall* during AMJ respectively (not shown).

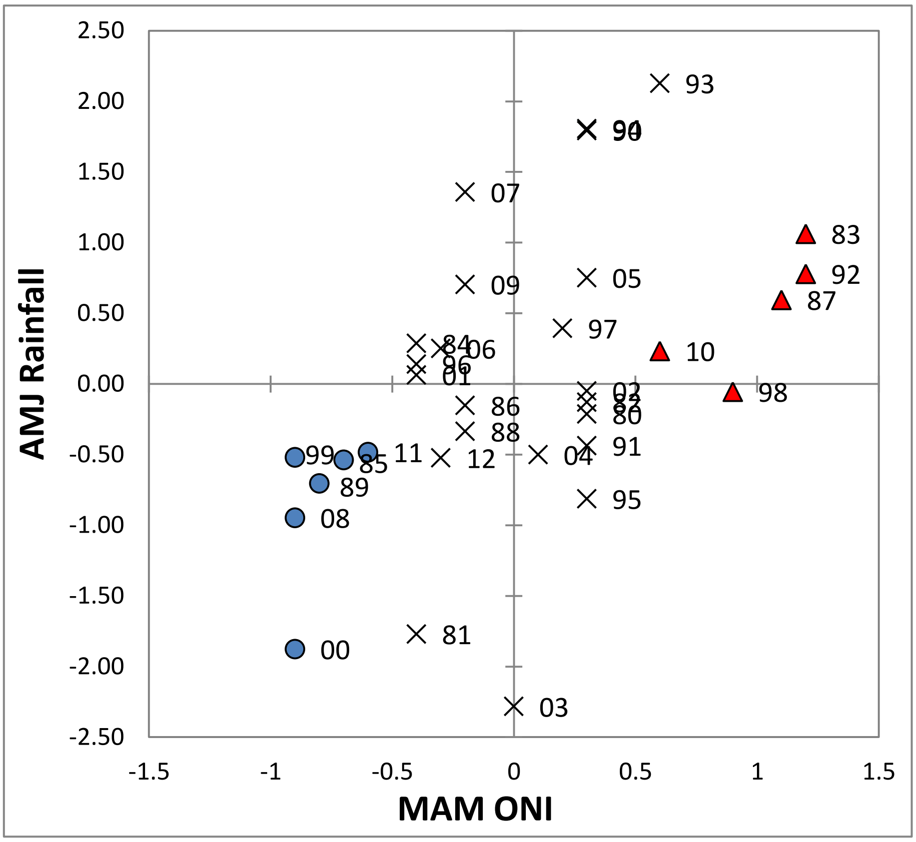

Figure 4.13: Area 3 AMJ *rainfall* from 1980-2012 against MAM ONI. Blue circles, red triangles and black crosses indicate La Niña, El Niño and ENSO-neutral years respectively.

The validity of two significant correlations seen in Table 4.9 (MAM ONI-AMJ Area 3 *rainfall* and MAM ONI-JAS Area 3 *rainfall*) were tested using composite plots of SST over the tropical Pacific derived from wet minus dry (above and below half a standard deviation away from mean) years (Figure 4.14). A clear warming (cooling) over the eastern and central equatorial pacific during the MAM period is evident for wet (dry) AMJ years in Area 3 (Figure 4.14a), supporting the significant positive correlation seen in Table 4.9. In the case of the significant negative correlation between MAM ONI and JAS *rainfall* in Area 2 the opposite is observed with SSTs over the central and eastern equatorial Pacific showing negative (positive) anomalies during wet (dry) years (Figure 4.14b). These results further demonstrate that the state of ENSO during the MAM period coincides with years of wet and dry rainfall during the beginning and end of the wheat growing season in Areas 2 and 3. Warmer SSTs during the MAM period coincide with years that experience above normal rainfall during the beginning of the winter season (especially Area 3) and below normal rainfall in the latter part of the winter season in both Areas 2 and 3. Together these results suggest that ENSO causes seasonal rainfall anomalies, either in the early or late season, depending on the mode. El Niño (La Niña) is associated with positive (negative) rainfall anomalies during early season and negative (positive) late season rainfall anomalies.

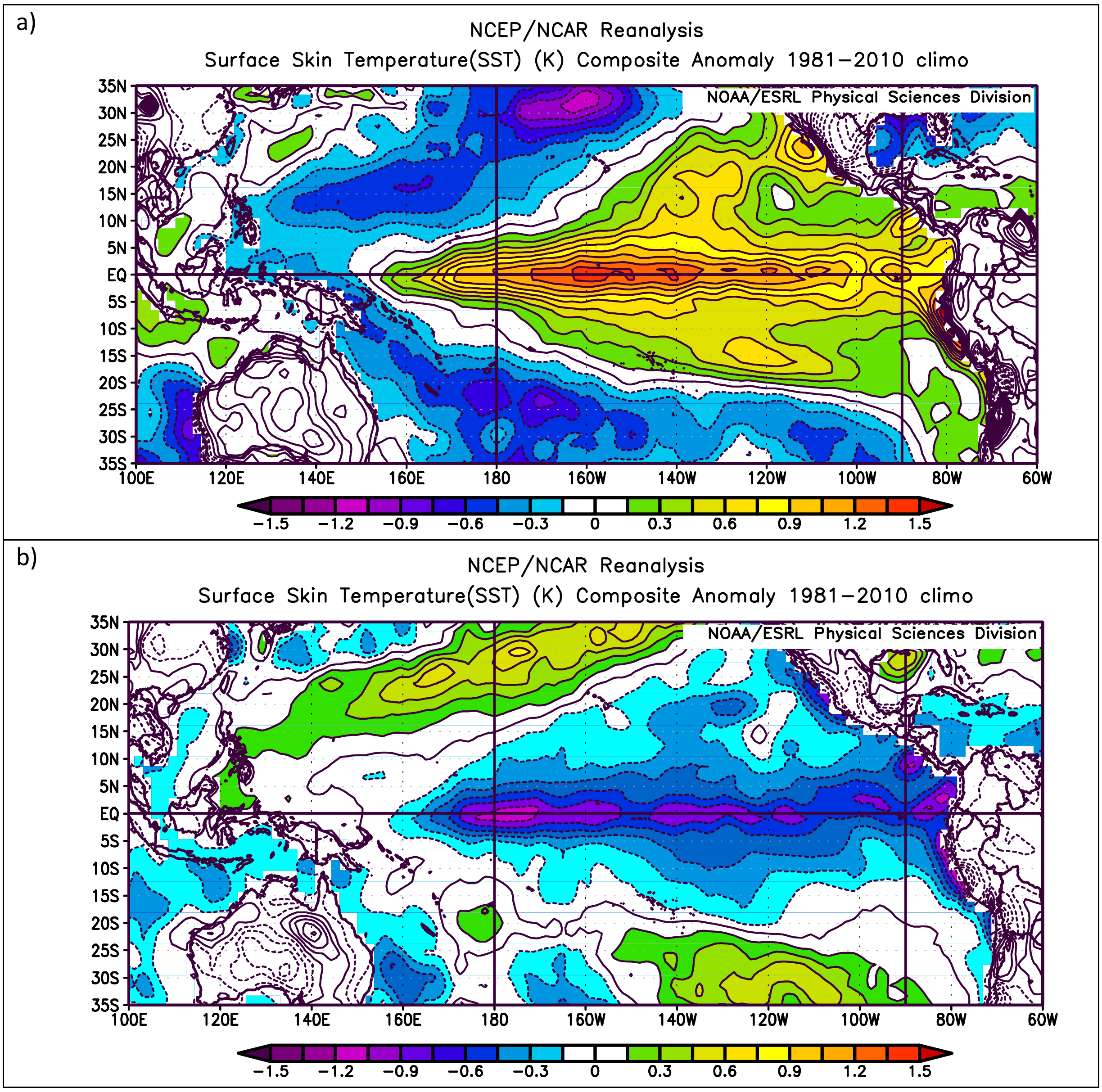

Figure 4.14 (a-b): Sea surface temperature (SST) composite plots in the tropical Pacific over the MAM period for years of **a)** wet minus dry AMJ *rainfall* from Area 3 and **b)** wet minus dry JAS *rainfall* from Area 2.

The significant correlations between the ENSO indices and *rainfall* during AMJ and MJJ concur with the findings of Philippon *et al.* (2011). Although not mentioned in the paper, it was discovered through correspondence with one of the authors of Philippon *et al.* (2011), Dr Mathieu Rouault, that they too found negative correlations between the Nino3.4 Index and rainfall during the latter seasonal periods.

The correlation results from Area 1, the most northern and driest of the three study areas, are somewhat unexpected as finding from the Philippon *et al.* (2011) suggested storm tracks shift equatorward during El Niño events increasing the rainfall at stations at lower latitudes along the western part of South Africa. The correlation coefficients between the ENSO indices and rainfall in Area 1 seem to oppose the finding from Areas 2 and 3, especially for the ONI and SOI indices. The SOI-*rainfall* correlation patterns from Area 1 are similar to those observed between the ONI and Nino3.4 Index and rainfall in Areas 2 and 3.

4.3.1.2 With additional rainfall characteristics

Five additional rainfall characteristics from each of the three areas were correlated against the three ENSO indices. For the full set of correlation coefficients between the five additional rainfall characteristics indices and ENSO indices see Appendix B.

The correlation patterns observed in the total *rainfall*-ENSO analysis (Table 4.9) were largely mirrored in the results of the correlation analysis of the *wet days* (daily rainfall >2mm), *'good' rainfall* (daily rainfall >10mm) and *percentage 'good' rainfall* (ratio of *'good' rainfall* events to *wet days*) against ENSO indices. The *heavy rainfall* (daily rainfall >25mm) Index across the three areas showed very few (six) significant correlations ($\rho<0.1$) with the ENSO indices. The *dry dekads* (dekad rainfall <10mm) Index showed significant correlations in Areas 1 (northern area) and 3 (western/coastal area).

Table 4.10 shows the summation of the five additional rainfall characteristics-ENSO analyses with the values indicating the number of instances of significant correlations. The table indicates periods of common association between the individual ENSO indices and particular periods of the rainfall characteristic indices across the three regions. In Area 3 the ONI during the AMJ period shows a significant correlation with four of the five additional rainfall characteristic indices during the same AMJ period. Elaborating on this, years that experience warmer SSTs over the Nino3.4 region (positive ONI/Nino3.4) during April-June coincide with year that experience more frequent and more substantial rainfall events, which are well distributed over the April-June period with fewer dry dekads occurring in Area 3.

Generally across the three areas the ENSO indices seem to show significant correlation during the latter periods of the wheat season with the rainfall characteristic indices, especially Area 2. These correlations occur during periods of the ENSO indices well in advance of the rainfall characteristic indices' periods. The first half of the wheat season does show significant correlations predominantly in Area 3 and is strongest at synchronous periods.

Table 4.10: Values indicate the number (count) of significant (ρ<0.1) Pearson's correlation coefficients obtained from comparing the three ENSO indices with the five wheat-specific rainfall characteristic indices over the 1980-2012 period for the three study areas.

ENSO		Area 1							Area 2							Area 3						
		MAM	AMJ	MJJ	JJA	JAS	ASO	SON	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	MAM	AMJ	MJJ	JJA	JAS	ASO	SON
NINO3.4	JFM	0	0	0	0	1	2	0	0	0	0	0	2	1	2	0	2	0	0	0	0	2
	FMA	0	0	0	0	1	1	0	0	0	0	0	3	2	2	0	2	2	0	1	0	2
	MAM	0	0	1	1	0	0	0	0	1	0	0	3	3	2	0	3	3	0	1	1	2
	AMJ		1	2	3	1	0	0		2	0	0	1	3	1		4	4	0	0	1	2
	MJJ			0	1	0	0	0			0	0	0	1	0			2	0	0	0	0
	JJA				0	0	1	0				0	0	0	0				0	0	0	0
	JAS					0	1	3					0	0	0					0	0	0
	ASO						1	0						0	0						0	0
ONI	JFM	0	0	0	0	0	1	3	0	0	0	0	2	1	2	0	2	0	0	1	0	2
	FMA	0	0	0	0	0	0	3	0	1	0	0	2	2	2	0	2	3	0	1	0	2
	MAM	0	0	0	0	0	0	1	0	1	0	0	3	3	2	0	3	3	0	1	1	2
	AMJ		0	1	0	0	0	2		1	0	0	2	3	1		4	3	0	1	1	0
	MJJ			1	0	0	0	0			0	0	0	1	0			2	0	0	0	0
	JJA				0	0	0	0				0	0	0	0				0	0	0	0
	JAS					0	0	0					0	0	0					0	0	0
	ASO						0	0						0	0						0	0
SOI	JFM	0	0	0	0	0	0	3	0	0	0	0	0	2	2	1	2	2	0	0	0	2
	FMA	0	0	0	0	1	0	3	0	0	0	0	0	0	2	0	2	1	0	0	0	2
	MAM	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	2	2	0	0	0	0
	AMJ		1	0	0	0	0	0		0	0	0	0	0	2		2	1	0	1	0	1
	MJJ			2	0	0	0	0			1	0	0	0	0			0	0	1	0	0
	JJA				0	0	0	0				0	0	0	2				0	1	0	2
	JAS					0	0	0					0	0	1					1	0	1
	ASO						0	0						0	1						0	1

4.3.2 Antarctic Oscillation

4.3.2.1 With total seasonal rainfall

Two climate indices were used to represent a low-frequency mode of atmospheric variability in the Southern Hemisphere known as the Antarctic Oscillation (AAO) or the Southern Annual Mode (SAM). These two indices were the AAO Index and the SAM Index (see Chapter 3 for definitions). Similar to the ENSO-*rainfall* analysis, the two AAO indices were correlated with *rainfall*, with Table 4.11 displaying the correlation coefficients between the AAO indices and the total seasonal (over lapping three month periods) *rainfall* for each of the three areas. In Table 10 the red (blue) highlighted coefficients indicate significant negative (positive) correlations with darker shades representing greater significance.

All significant correlations (ρ<0.1) between the AAO indices and *rainfall* throughout the three areas in Table 4.11 are negative, with the exception of two instances that occur between rainfall from Area 1 and the SAM Index. This suggests rainfall in the Swartland is higher (lower) during periods when the AAO/SAM is negative (positive), which is consistent with the findings of previous studies by Reason *et al.* (2002) and Reason & Jagadheesha (2005) whose work focused on the entire winter rainfall region of South Africa. According to the literature a negative (positive) phase of AAO/SAM indicates the occurrence of a weakening (strengthening) circumpolar vortex and zonal (westerly) winds that circle Antarctica (Marshall 2003). A negative (positive) AAO/SAM phase is associated with an equatorward (poleward) shift in the mid-latitude storm tracks (Kidson & Sinclair 1995) increasing the number of rain bearing frontal systems to make landfall over the south western tip of Africa.

The AAO Index displays stronger (more significant) correlations with *rainfall* from Area 2 with only one significant correlation between the AAO Index and each of Areas 1 and 3. Comparing the AAO and SAM indices, the SAM Index shows a greater number of significant correlations throughout each of the three areas. Although these two indices attempt to capture the same physical process by definition they differ from one other. In a study by Ho *et al.* (2012) the authors extensively examined all the indices created and used in the literature to describe the SAM. They found the differences between these indices were dependant of the method, variable, or source of data used to develop the index. The AAO and SAM indices used in this study intentionally differ in their method, variable and source producing expectantly different records, which allow potential uncertainty in the SAM definition to be captured.

Table 4.11: Pearson's correlation coefficients obtained from comparing two AAO indices with rainfall over the 1980-2012 period from the three study areas. Highlighted coefficients are significant at the 10% significance level with darker shadings indicating greater significance (see key).

AAO		Area 1 Rainfall						Area 2 Rainfall						Area 3 Rainfall					
		AMJ	MJJ	JJA	JAS	ASO	SON	AMJ	MJJ	JJA	JAS	ASO	SON	AMJ	MJJ	JJA	JAS	ASO	SON
AAO	JFM	-0.016	0.053	0.095	0.028	-0.127	0.038	-0.113	-0.095	0.003	-0.001	-0.080	0.047	-0.134	-0.088	0.002	0.000	-0.100	0.076
	FMA	0.004	-0.077	-0.200	-0.102	-0.182	-0.114	-0.022	-0.137	-0.205	-0.128	-0.138	-0.234	0.015	-0.029	-0.075	-0.065	-0.140	-0.195
	MAM	-0.091	-0.198	-0.253	-0.122	-0.023	0.040	-0.220	-0.316	-0.349	-0.175	-0.019	-0.085	-0.147	-0.166	-0.169	-0.078	0.009	-0.054
	AMJ	-0.116	-0.162	-0.274	-0.032	0.003	0.020	-0.265	-0.273	-0.377	-0.083	0.008	-0.002	-0.239	-0.172	-0.226	0.020	0.038	0.002
	MJJ		-0.096	-0.261	-0.035	0.002	-0.021		-0.248	-0.384	-0.070	0.011	-0.009		-0.199	-0.303	-0.012	0.026	0.023
	JJA			-0.233	-0.076	-0.126	-0.164			-0.285	-0.103	-0.122	-0.201			-0.148	-0.013	-0.068	-0.118
	JAS				-0.104	-0.198	-0.312				-0.101	-0.175	-0.427				0.014	-0.091	-0.286
	ASO					-0.225	-0.218					-0.257	-0.350					-0.139	-0.253
	SON						-0.103						-0.182						-0.106
SAM	JFM	0.095	-0.052	-0.261	-0.335	-0.180	-0.163	-0.053	-0.090	-0.023	-0.143	-0.265	-0.041	-0.053	-0.089	-0.062	-0.173	-0.324	-0.102
	FMA	0.162	0.002	-0.251	-0.355	-0.217	-0.174	0.089	-0.127	-0.121	-0.207	-0.248	-0.310	0.094	-0.089	-0.101	-0.193	-0.280	-0.358
	MAM	0.272	0.128	-0.150	-0.348	-0.285	-0.193	-0.266	-0.360	-0.336	-0.147	0.044	-0.077	-0.199	-0.246	-0.211	-0.069	0.059	-0.063
	AMJ	0.361	0.251	0.054	-0.283	-0.307	-0.199	-0.280	-0.258	-0.399	-0.102	0.024	0.090	-0.303	-0.251	-0.351	-0.023	0.076	0.095
	MJJ		0.274	0.229	-0.135	-0.207	-0.142		-0.167	-0.386	-0.097	-0.039	0.114		-0.162	-0.347	-0.041	0.007	0.145
	JJA			0.325	-0.025	-0.108	-0.107			-0.251	-0.158	-0.235	-0.254			-0.108	-0.056	-0.149	-0.189
	JAS				-0.008	-0.078	-0.102				-0.168	-0.254	-0.583				-0.015	-0.155	-0.455
	ASO					-0.100	-0.125					-0.225	-0.348					-0.113	-0.245
	SON						-0.120						-0.144						-0.064

Table 4.11 Key

ρ value	Value		Significance
	Negative	Positive	
0.1	-0.2913	0.2913	10.00%
0.05	-0.3440	0.3440	5.00%
0.02	-0.4032	0.4032	2.00%
0.01	-0.4421	0.4421	1.00%
0.005	-0.4770	0.4770	0.50%
0.002	-0.5184	0.5184	0.20%

As observed in the ENSO-*rainfall* analysis, Areas 2 and 3 show similar significant correlation patterns. *Rainfall* during the JJA and SON seasons show strong correlations with the AAO and SAM indices for preceding periods. The strongest correlation occurs between the SON *rainfall* in Area 2 and the JAS SAM Index (r= -0.583, ρ<0.001) and is inspected further in Figure 4.15. Of the 18 (15) years to have experienced positive (negative) SAM over the JAS period, 15 (10) experienced above normal rainfall during the SON period in Area 2.

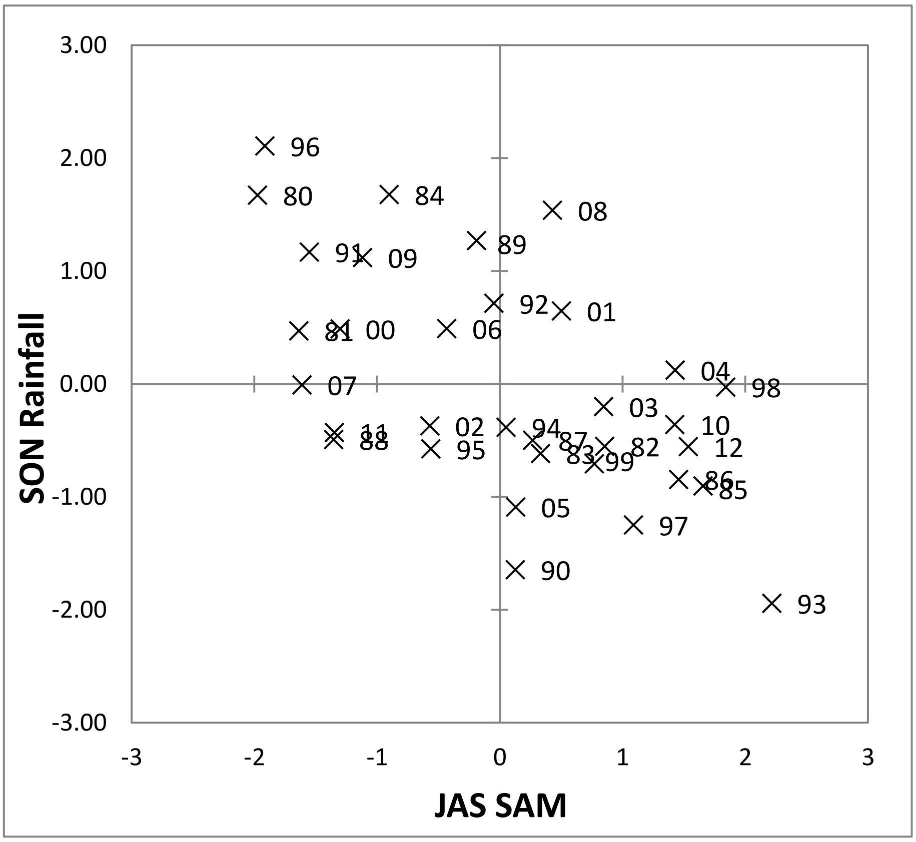

Figure 4.15: Area 2 SON *rainfall* from 1980-2012 against the JAS SAM.

The two composite plots in Figure 4.16 examine the atmospheric dynamics of the Southern Hemisphere and corroborate the significant correlations observed in Table 4.11. In the composite anomaly plot of the 700mb GpH (the 700mb GpH level is the level used to create the AAO Index and so easier to distinguish the pressure pattern compared with the surface level) during JAS for wet minus dry years of Area 2 SON *rainfall* (Figure 4.16a), anomalously high pressures are observed over the Antarctic and anomalously low pressures in the mid-latitudes, a characteristic pattern of a negative AAO/SAM phase (Ho *et al.* 2012). This result indicates negative (positive) AAO/SAM during JAS is associated with wet (dry) SON years in Area 2, confirming the significant negative correlation. A similar 700mb geopotential height [GpH] anomaly pattern is evident in Figure 4.16b, once again corroborating the significant correlation observed between the AMJ SAM and the JJA *rainfall* in Area 2.

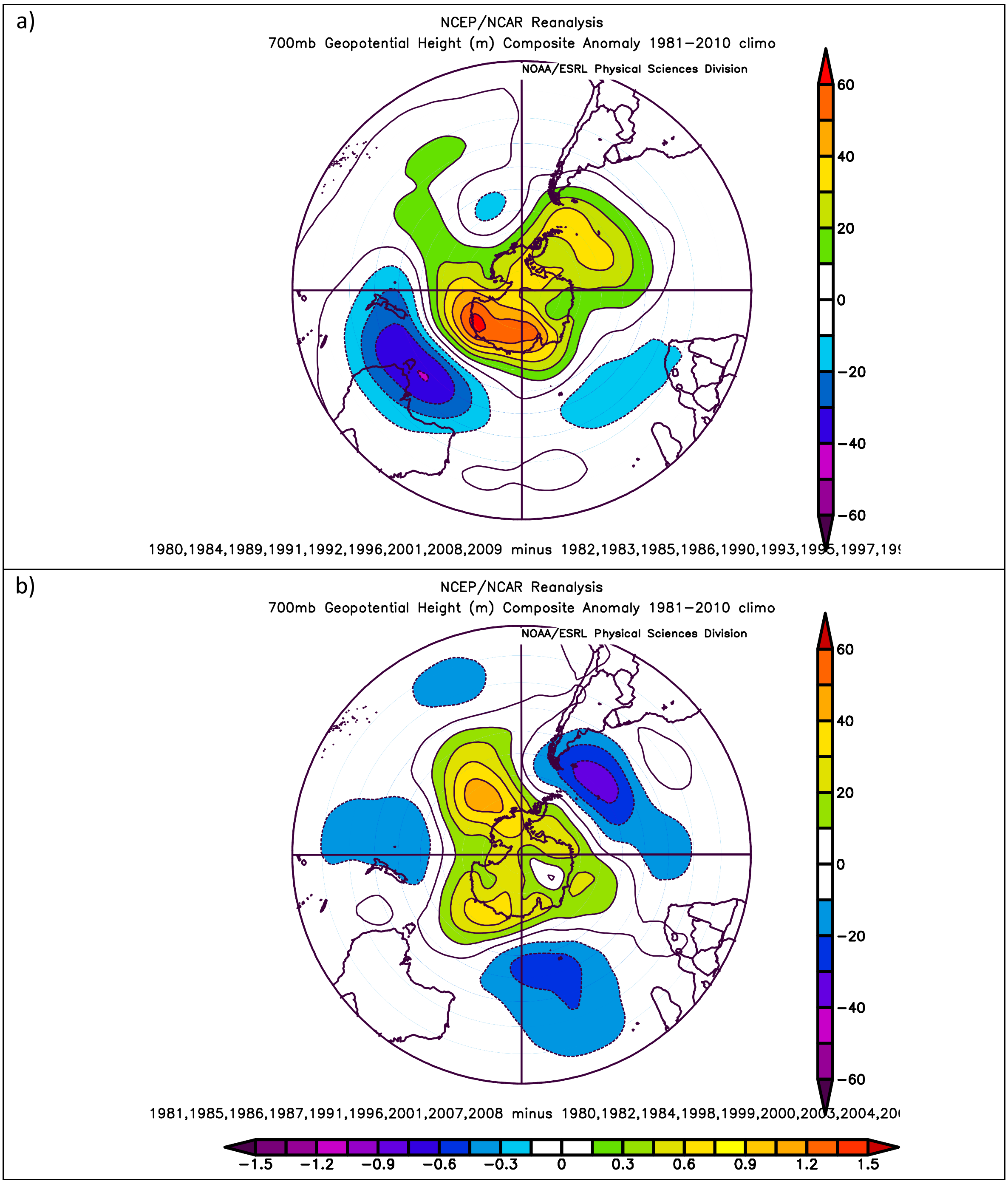

Figure 4.16 (a-b): 700mb Geopotential height (GpH) composite plots in the Southern Hemisphere, **a)** over the JAS period for years of wet minus dry SON *rainfall* from Area 2 and **b)** over the AMJ period for years of wet minus dry JJA *rainfall* from Area 2.

4.3.2.2 With additional rainfall characteristics

The five additional rainfall characteristics from each of the three areas were correlated against the two AAO indices. For the full set of correlation coefficients between the five additional rainfall characteristics indices and AAO indices see Appendix C.

Table 4.12 shows the summation of the five additional rainfall characteristics-AAO analyses with the values indicating instances of significant ($\rho<0.1$) correlations. The table indicates periods of common association between the individual AAO indices and particular periods of the rainfall characteristic indices across the three regions. The large proportion of low ($\leq$ 2) to high ($\geq$ 3) values in Table 4.12 indicates the variety of the significant correlation patterns between the AAO indices and the rainfall characteristic indices, i.e. there are very few instance where a specific period of the AAO indices show significant correlations with a specific period for more than two out of the five additional rainfall characteristic indices. The SON period shows significant correlation with the JAS and ASO periods of the SAM of four of the five additional rainfall characteristic indices from Area 2. This result indicates years that experience an expansion of the strong westerly wind belt around Antarctica towards the equator (negative SAM) over the July-October period coincide with years that experience an increase in the number of wet days and 'good' rainfall events, with a better proportion of 'good' rainfall events to wet days and fewer dry dekads during the SON period in Area 2. This is not necessarily useful for the farmers as their wheat requires ample September rainfall but not rainfall over the October-November period as it could cause disease and/ or sprouting in the crop drying in the fields. Therefore, the seasonal (three month) periods that do not include September and October would provide a clearer message for wheat farmers.

Table 4.12: Values indicate the number (count) of significant (ρ<0.1) Pearson's correlation coefficients obtained from comparing the two AAO indices with the five wheat-specific rainfall characteristic indices over the 1980-2012 period for the three study areas. Darker shading indicates a higher value.

AAO		Area 1							Area 2							Area 3						
		MAM	AMJ	MJJ	JJA	JAS	ASO	SON	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	MAM	AMJ	MJJ	JJA	JAS	ASO	SON
AAO	JFM	0	0	0	0	0	0	0	1	1	1	0	0	0	1	2	0	0	0	0	0	1
	FMA	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	0	2
	MAM	0	0	0	1	0	0	0	0	0	0	2	1	0	0	0	1	0	1	0	0	0
	AMJ		0	0	2	1	0	0		0	0	2	1	0	0		1	0	1	0	0	0
	MJJ			0	2	0	0	0			0	2	0	0	0			0	1	0	0	1
	JJA				0	0	0	0				1	0	1	0				0	0	0	1
	JAS					0	0	1					1	1	3					0	0	3
	ASO						1	0						3	2						1	1
	SON							0							0							0
SOI	JFM	0	0	0	0	0	0	2	1	0	0	0	1	1	0	2	0	1	0	1	1	0
	FMA	0	0	0	0	0	0	3	0	0	1	0	1	0	2	0	0	2	0	2	1	2
	MAM	0	0	0	0	0	1	3	0	1	1	2	1	0	0	0	1	1	2	0	0	0
	AMJ		1	0	0	0	2	1		0	1	2	1	0	0		0	1	2	0	0	0
	MJJ			1	0	0	0	0			0	2	1	0	0			1	1	0	0	1
	JJA				1	0	0	0				0	1	2	1				0	0	1	1
	JAS					0	0	0					1	1	4					0	0	3
	ASO						0	0						2	4						0	0
	SON							0							2							0

4.3.3 South Atlantic sea surface temperatures

4.3.3.1 With total seasonal rainfall

In order to analyse the effects of South Atlantic SSTs on winter *rainfall* in the Swartland, three indices were created. These three indices were the South Atlantic Dipole Index (SADI), the South Western Atlantic Index (SWAI) and the South Central Atlantic Index (SCAI) (see Chapter 3 for definitions). Similar to the two previous analyses the three South Atlantic SST indices were correlated with *rainfall*, with Table 4.13 displaying the correlation coefficients between the indices and the total seasonal (over lapping three month periods) *rainfall* for each of the three areas. In Table 4.13 the red (blue) highlighted coefficients indicate significant negative (positive) correlations with darker shades representing greater significance.

The SWAI and SCAI cover two regions in the South Atlantic Ocean, which were shown by Reason *et al.* (2002) to influence winter rainfall in South Africa and used in a modelling study by Reason and Jagadheesha (2005). From Table 4.13 the SCAI is shown to have significant negative correlations with JAS and ASO *rainfall* across the entire Swartland region. These results suggests years that experienced cooler (warmer) SST anomalies over the central South Atlantic Ocean over the MJJ-JAS and MAM-ASO periods coincided with years that experienced higher (lower) than normal rainfall in the Swartland region during the JAS and ASO periods respectively. The strongest negative correlation, between rainfall from Area 2 during the JAS period and the SCAI during the same period, can be seen in Figure 4.17.

Figure 4.18 examines two specific significant correlations observed between the JAS SCAI and the; JAS *rainfall* from Area 2 (Figure 4.18a; r= -0.532, $\rho<0.0025$) and ASO *rainfall* from Area 3 (Figure 4.18b; r= -0.479, $\rho<0.005$). Both composite plots in Figure 4.18 show anomalously cooler SSTs over the central South Atlantic (SCAI uses 36°-44°S, 0°E-18°W) during the JAS period confirming the correlation findings.

These results are in agreement with the studies of Reason *et al.* (2002) and Reason and Jagadheesha (2005). Reason *et al.* (2002) postulated that the anomalously cool SSTs in the central South Atlantic result in an equatorward shift of the mean westerly flow. This shift causes storms to track along lower latitudes than average, increasing the frequency of rain bearing systems, therefore, rainfall in the South Western Cape (SWC) (Reason *et al.* 2002). The two papers (Reason *et al.* 2002; Reason & Jagadheesha 2005) gave evidence that suggested warmer SST anomalies in the western South Atlantic coincided with years that experienced higher rainfall in the winter rainfall region of South Africa. The warmer SSTs were hypothesized to aid cyclogenesis of the mid-latitude cyclones, increasing the frequency and intensity of the developing depressions (Reason *et al.* 2002). However, from the results in Table 4.13 this influence of the SSTs in the western South Atlantic on the winter *rainfall* in the Swartland is not observed. In fact no significant ($\rho<0.1$) correlation occurs between the SWAI and *rainfall* across any of the three areas in the study region.

The SADI was created by subtracting the SCAI from the SWAI (see Chapter 3 for methodology). Therefore, as product of its design, with the SCAI showing strong correlations and the SWAI weak, the SADI is an opposite and generally slightly weaker reflection of the SCAI.

Table 4.13 Key

ρ value	**Value**		**Significance**
	Negative	Positive	
0.1	-0.2913	0.2913	10.00%
0.05	-0.3440	0.3440	5.00%
0.02	-0.4032	0.4032	2.00%
0.01	-0.4421	0.4421	1.00%
0.005	-0.4770	0.4770	0.50%
0.002	-0.5184	0.5184	0.20%

Table 4.13: Pearson's correlation coefficients obtained from comparing three South Atlantic sea surface temperature indices with rainfall over the 1980-2012 period from the three study areas. Highlighted coefficients are significant at the 10% significance level with darker shadings indicating greater significance (see key).

S. Atlantic SSTs		Area 1 Rainfall					Area 2 Rainfall					Area 3 Rainfall				
		AMJ	MJJ	JJA	JAS	ASO	AMJ	MJJ	JJA	JAS	ASO	AMJ	MJJ	JJA	JAS	ASO
SADI	JFM	-0.008	-0.090	-0.200	-0.153	0.137	0.159	0.090	-0.141	-0.172	0.058	0.238	0.160	-0.069	-0.132	0.149
	FMA	-0.084	-0.093	-0.114	-0.055	0.161	0.098	0.084	-0.004	-0.060	0.153	0.155	0.107	0.043	-0.023	0.247
	MAM	-0.180	-0.110	-0.020	0.015	0.189	-0.034	-0.008	0.039	-0.031	0.191	0.028	0.008	0.076	-0.014	0.251
	AMJ	-0.325	-0.118	0.121	0.184	0.248	-0.204	-0.062	0.136	0.116	0.254	-0.139	-0.044	0.148	0.109	0.275
	MJJ		-0.106	0.170	0.330	0.248		-0.063	0.198	0.275	0.262		-0.023	0.209	0.277	0.281
	JJA			0.190	0.466	0.290			0.308	0.462	0.332			0.286	0.466	0.367
	JAS				0.492	0.316				0.536	0.366				0.537	0.422
	ASO					0.364					0.389					0.426
SWAI	JFM	0.033	-0.031	-0.060	-0.069	0.045	0.176	0.132	-0.071	-0.087	-0.033	0.143	0.043	-0.147	-0.084	0.054
	FMA	0.013	0.027	0.066	0.014	0.006	0.136	0.168	0.090	0.012	0.005	0.087	0.058	0.007	0.040	0.125
	MAM	0.034	0.032	0.155	-0.041	-0.068	0.054	0.047	0.098	-0.078	-0.062	0.020	-0.033	0.048	-0.054	0.018
	AMJ	-0.047	0.004	0.214	-0.002	-0.037	-0.089	-0.050	0.093	-0.058	-0.039	-0.089	-0.082	0.062	-0.063	-0.013
	MJJ		-0.089	0.143	0.016	-0.055		-0.165	0.027	-0.035	-0.066		-0.130	0.035	-0.041	-0.067
	JJA			0.089	0.153	0.020			0.069	0.134	0.024			0.081	0.133	0.030
	JAS				0.183	0.032				0.223	0.058				0.255	0.111
	ASO					0.157					0.175					0.226
SCAI	JFM	0.036	0.085	0.196	0.133	-0.134	-0.055	-0.006	0.117	0.142	-0.098	-0.180	-0.162	-0.032	0.096	-0.141
	FMA	0.115	0.138	0.196	0.080	-0.198	-0.014	0.029	0.078	0.085	-0.187	-0.125	-0.089	-0.048	0.061	-0.208
	MAM	0.254	0.164	0.157	-0.056	-0.294	0.090	0.051	0.036	-0.029	-0.291	-0.017	-0.039	-0.054	-0.029	-0.295
	AMJ	0.377	0.158	0.047	-0.244	-0.357	0.183	0.036	-0.087	-0.209	-0.366	0.097	-0.021	-0.133	-0.203	-0.367
	MJJ		0.055	-0.090	-0.420	-0.374		-0.073	-0.236	-0.398	-0.402		-0.091	-0.241	-0.405	-0.429
	JJA			-0.176	-0.494	-0.377			-0.357	-0.508	-0.431			-0.315	-0.514	-0.472
	JAS				-0.508	-0.404				-0.532	-0.450				-0.507	-0.479
	ASO					-0.380					-0.397					-0.404

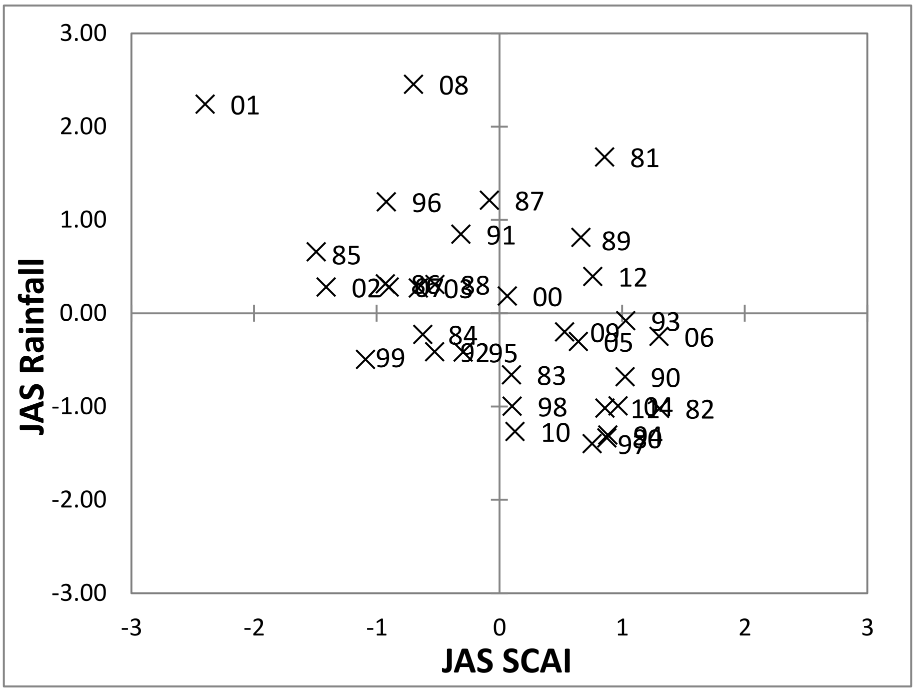

Figure 4.17: Area 2 JAS *rainfall* from 1980-2012 against the JAS SCAI.

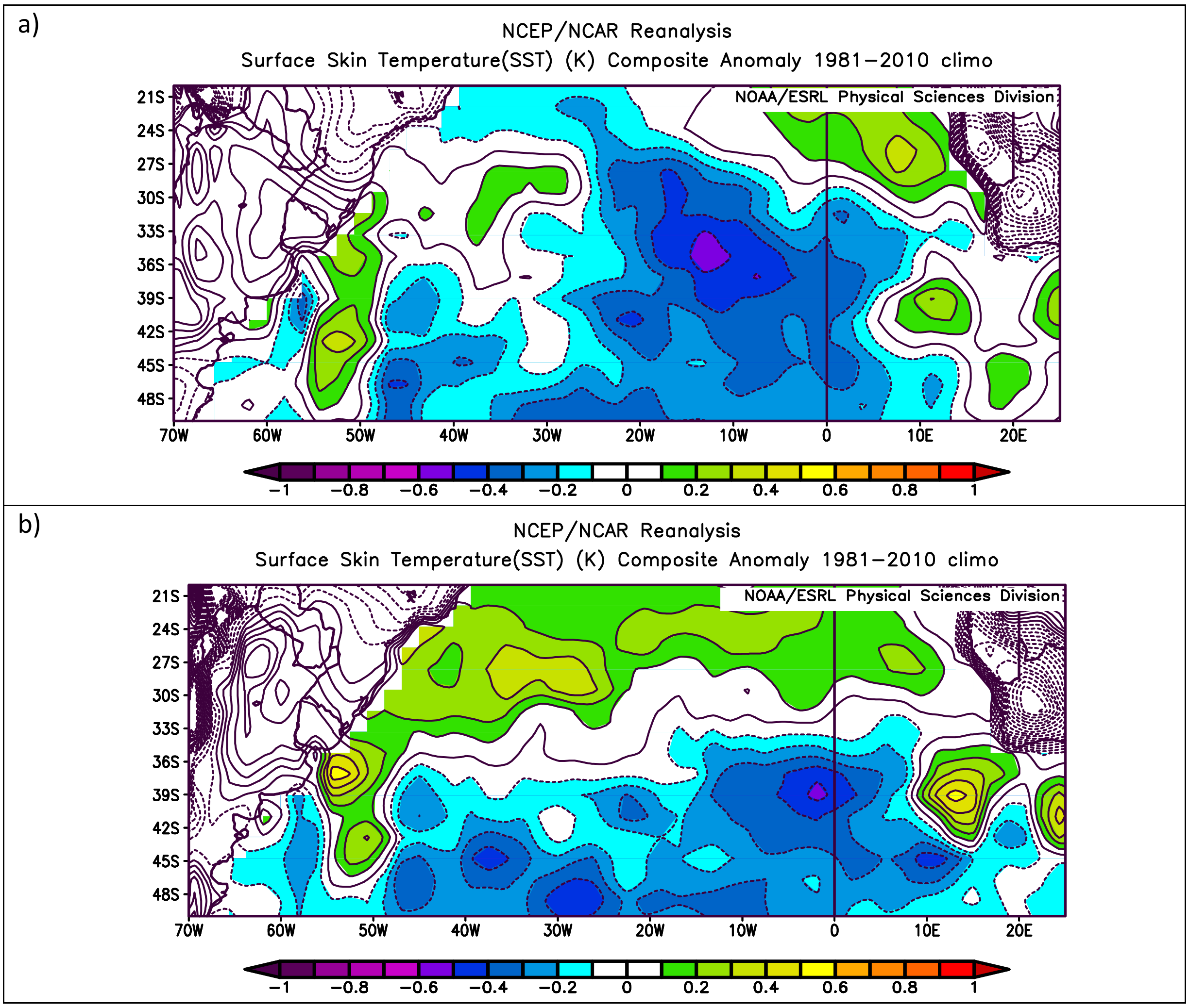

Figure 4.18 (a-b): Sea surface temperature (SST) composite plots in the South Atlantic over the JAS period for years of **a)** wet minus dry JAS *rainfall* from Area 2 and **b)** wet minus dry ASO *rainfall* from Area 3.

4.3.3.2 With additional rainfall characteristics

The five additional rainfall characteristics from each of the three areas were correlated against the three South Atlantic SST indices. For the full table of correlation coefficients between the five additional rainfall characteristics indices and Atlantic indices see Appendix D.

Table 4.14 shows the summation of the five additional rainfall characteristics-Atlantic SST analyses with the values indicating instances of significant ($\rho<0.1$) correlations. The table indicates periods of common association between the individual Atlantic SST indices and particular periods of the rainfall characteristic indices across the three regions. Table 4.14 reiterates the lack of significant SWAI correlations from the *rainfall* analysis, with only eight significant correlations observed between the SWAI and the five additional rainfall characteristic indices. The lack of correlation in the SWAI equates to the SADI being a reflection of the SCAI; therefore, only the SCAI will be discussed.

The SCAI shows significant correlation with the rainfall characteristic indices predominantly over the latter half of the wheat growing season from July to November. The SSTs over the central South Atlantic during the JJA and JAS period are significantly correlated with all five of the rainfall characteristic indices from Area 3 and four of the five from Area 2 during the JAS period.

Table 4.14: Values indicate the number (count) of significant (ρ<0.1) Pearson's correlation coefficients obtained from comparing the three South Atlantic SST indices with the five wheat-specific rainfall characteristic indices over the 1980-2012 period for the three study areas. Darker shading indicates a higher value.

S. Atlantic SST		Area 1							Area 2							Area 3						
		MAM	AMJ	MJJ	JJA	JAS	ASO	SON	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	MAM	AMJ	MJJ	JJA	JAS	ASO	SON
SADI	JFM	0	0	0	0	0	1	1	0	0	1	0	0	0	2	1	1	1	1	0	0	0
	FMA	0	0	0	0	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	1	0
	MAM	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	AMJ		1	0	0	0	1	1		0	0	0	0	0	1		0	0	0	0	2	2
	MJJ			0	0	0	1	1			0	0	0	1	1			0	0	1	2	2
	JJA				0	2	1	0				2	3	1	1				1	4	2	1
	JAS					1	1	0					3	2	0					5	2	0
	ASO						1	0						2	0						3	0
SWAI	JFM	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	FMA	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	MAM	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	AMJ		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0
	MJJ			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0
	JJA				0	0	1	0				0	0	0	0				0	0	0	0
	JAS					0	1	0					0	0	1					0	0	0
	ASO						0	0						0	0						0	0
SCAI	JFM	0	0	0	0	0	1	0	0	0	0	0	0	0	2	2	0	1	1	0	0	0
	FMA	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
	MAM	1	2	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0
	AMJ		3	0	0	1	2	1		0	0	0	1	1	0		0	0	0	3	3	1
	MJJ			0	0	3	1	1			0	0	4	2	0			0	0	4	3	2
	JJA				0	3	2	1				1	4	3	0				1	5	3	2
	JAS					2	2	2					4	3	1					5	3	2
	ASO						1	2						3	0						3	1

4.3.4 Correlation summation

The correlation analysis produced 3744 correlation coefficients between the six rainfall characteristic indices (including total *rainfall*) and the eight climate indices. The sheer number of correlations makes summarising their significance difficult. To do this a correlation summation table was created, which sums all the significant correlations that occurred during a particular trimonthly period between the climate and rainfall characteristic indices for each of the three areas. A simple summation of the significant correlations, however, would be misleading as the eight climate indices are not evenly distributed across the three teleconnections, which would have resulted in over and under representation of particular teleconnections. To account for this a weighting system was used. The significant correlation counts were weighted so that each teleconnection could have a maximum of one significant correlation per trimonthly period per rainfall characteristic index per area. Each of the three ENSO indices were multiplied by 1/3 and each of the two AAO indices multiplied by 1/2. With the SWAI showing close to no significant correlations it was decided to remove the SWAI and the SADI, which mirrored the SCAI by design. Only the SCAI was used in the summation table (having a weighting of 1). The significant correlations for each of the six rainfall characteristic indices were deemed equal, i.e. no one rainfall characteristic was thought to be more important, as the importance of each was not established and exceeded the scope of this study. The weighted counts of significant correlations were then summed.

This resulted in a correlation summation table (Table 4.15) for each of the three areas with values ranging from 0 to 18 (three teleconnections by six rainfall characteristic indices). The shading in Table 4.15 is indicative of the size of the value with darker shading indicating larger numbers. It is important to state this method of data representation can be misleading as it may hide important relationships that may only affect one rainfall characteristic. It also assumes that the teleconnections themselves are reasonably independent of each other. This table also does not offer any information regarding the nature of the correlation found between the teleconnections and the rainfall characteristics, never the less it does help to identify periods where associations between the teleconnections and rainfall characteristics in the each of the three areas are reasonably strong.

Area 1 does not show as many significant correlations as Areas 2 and 3. The rainfall characteristics during the latter half of the winter wheat season (JAS, ASO and SON) in Area 2 show the largest number of associations with the three teleconnections. The rainfall characteristics in Area 3 on the other hand show association with the teleconnections throughout the winter wheat season.

Table 4.15: The number of significant correlations (ρ<0.1) between the eight climate indices and the six rainfall characteristic indices in each of the three areas. Darker shading indicates higher number of significant correlations.

Area 1		**Rainfall Characteristic Indices**											
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
Climate Indices	JFM	0.0	0.0	0.0	0.0	0.0	0.0	1.2	2.3	3.0	0.0	0.0	2.0
	FMA		0.7	0.0	0.0	0.0	0.0	1.5	1.7	3.5	0.0	0.0	1.0
	MAM			1.0	2.0	0.3	0.8	1.2	3.5	2.5	0.0	0.0	0.0
	AMJ				6.0	1.0	2.3	2.2	4.5	2.2	0.3	0.5	0.0
	MJJ					1.5	1.3	4.0	2.0	1.0	0.0	0.3	0.0
	JJA						1.0	4.0	3.7	1.3	0.0	0.7	0.5
	JAS							3.0	3.3	5.3	0.7	1.2	2.8
	ASO								2.8	3.0	0.0	0.0	2.8
	SON									1.0	0.0	0.0	1.8
	OND										0.0	0.3	0.8
	NDJ											0.3	0.8
	DJF												1.2

Area 2		**Rainfall Characteristic Indices**											
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
Climate Indices	JFM	0.0	0.3	1.0	0.5	0.5	0.0	2.8	1.8	4.8	0.0	0.0	0.0
	FMA		0.7	0.0	0.3	0.5	0.5	3.3	2.0	5.2	0.0	3.5	1.0
	MAM			0.0	1.8	1.5	3.0	3.7	3.7	1.7	0.0	0.5	0.0
	AMJ				1.7	0.5	3.0	3.7	4.7	1.7	1.0	0.5	0.0
	MJJ					0.3	3.0	5.5	4.0	0.0	1.0	0.5	0.0
	JJA						2.5	5.5	5.5	1.5	1.0	0.0	0.5
	JAS							6.0	5.0	5.8	4.0	4.0	2.0
	ASO								6.5	4.3	0.0	0.0	1.0
	SON									1.0	0.0	1.0	1.0
	OND										0.0	1.0	1.0
	NDJ											2.0	1.0
	DJF												1.5

Area 3		**Rainfall Characteristic Indices**											
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
Climate Indices	JFM	0.0	0.0	5.7	3.0	2.2	1.0	1.5	1.0	2.8	1.0	0.0	1.5
	FMA		0.0	1.0	3.0	3.7	1.0	3.3	1.2	5.5	2.5	2.0	1.5
	MAM			0.0	4.7	4.2	2.5	2.3	2.3	2.0	0.0	0.5	3.5
	AMJ				5.3	4.2	2.0	4.0	5.3	2.3	0.0	0.0	2.3
	MJJ					2.5	2.3	5.3	4.0	3.0	0.0	0.0	3.0
	JJA						2.7	6.3	4.5	3.7	0.0	0.0	1.5
	JAS							6.3	4.0	5.8	4.0	2.5	0.0
	ASO								4.5	1.8	0.0	0.0	0.0
	SON									0.0	0.0	0.0	0.0
	OND										0.0	0.0	0.0
	NDJ											0.0	0.0
	DJF												1.0

CHAPTER 5: DISCUSSION AND CONCLUSION

This chapter is divided into four sections. Sections 5.1, 5.2 and 5.3 each deal with an analysis that was designed and conducted to accomplish the corresponding objective outlined in Chapter 1. The key findings from each of the analyses are summarised and their contributions to the objectives are discussed. The limitations of each of these analyses are outlined. The possible application of these findings to wheat farmers in the Swartland region is presented.

The final section (5.4) highlights the impacts of climate on wheat production in the Swartland region, and the relevance of the findings for wheat farmers, particularly the potential to aid farm management decisions. Recommendations for future work that can address the study's limitations are made.

5.1 Association of precipitation with wheat yields

This section addresses the first objective of the thesis, which was to elucidate the relationship between wheat-specific rainfall characteristics and wheat yields within the Swartland region of the Western Cape province of South Africa.

As explained previously, this section of the analysis focused exclusively on Area 2 (eastern Swartland region, inland) for the 1994 to 2010 period. Six wheat-specific rainfall characteristics were examined against wheat yields on various time scales, as listed below.

Wheat-specific rainfall characteristics:

- total *rainfall*
- number of *wet days* (daily rainfall >2mm)
- number of *'good' rainfall* events (daily rainfall >10mm)
- number of *heavy rainfall* events (daily rainfall >25mm)
- *percentage 'good' rainfall* (percentage of 'good' rainfall events to number of wet days)
- number of *dry dekads* (dekad rainfall <10mm])

Time scales:

- winter (April to September)
- seasonal; early (April to June) and late (July to September)
- monthly
- dekadal (10 day periods)

Four of the selected rainfall characteristics during the winter seasonal time scale showed significant correlation with wheat yield, as listed below.

- total *rainfall* (r=0.424, ρ<0.1)
- *wet days* (r=0.477, ρ<0.1)
- *'good' rainfall* (r=0.462, ρ<0.1)
- *dry dekads* (r=0.441, ρ<0.1)

Although these correlations described general relationships between the rainfall characteristics and wheat yields, a number of years did not conform. In an attempt to improve the understanding of the rainfall characteristic-wheat yield relationships, the temporal scale was increased from seasonal to monthly. On the seasonal time scale, only early (Apr-Jun) *'good' rainfall* (r=0.522, ρ<0.05) and early *percentage 'good' rainfall* (r=0.445, ρ<0.1) were shown to have significant correlations with wheat yields. When the temporal scale was increased to monthly, significant correlations were observed between wheat yields and;

- the total *rainfall* during May (r=0.578, ρ<0.025);
- the number of *wet days* during April (r=0.568, ρ<0.025) and May (r=0.589, ρ<0.025);
- the number of *'good' rainfall* events during April (r=0.512, ρ<0.05) and May (r=0.428, ρ<0.1);
- the *percentage of 'good' rainfall* during April (r=0.626, ρ<0.01);
- the number of *dry dekads* during May (r=0.518, ρ<0.05) and July (r=0.543, ρ<0.05).

The significant correlations from the monthly rainfall characteristic-wheat yield analysis support the idea that rainfall is a key determinant of wheat yield. However, the monthly rainfall characteristic-wheat yield correlations were unable to explain the wheat yields in some years. In an attempt to resolve such limits, sub-monthly rainfall characteristics were investigated.

The evaluation of sub-monthly rainfall's impact on wheat yields was carried out using farmer specified rainfall-wheat thresholds on the dekadal scale. Through discussions with Swartland wheat farmers and agricultural experts, three climatic thresholds were identified and assessed using dekadal rainfall and wheat yield data. These thresholds helped to identify the major finding from this section of the analysis, which is the importance of the distribution and timing of the rainfall throughout the wheat growing season on the wheat yield. This finding was not particularly surprising, considering the conversations with wheat farmers, but nevertheless is an important one, as no previous studies have attempted to link the impact of rainfall characteristics on wheat yield in the Western Cape.

5.1.1 Application to farmers

After adjustments were made to the thresholds (due to slight over estimations from farmers, with some thresholds never being met throughout the study period), the thresholds (listed below) were used to create a subjective model that relates these thresholds to the expected wheat yield.

- Threshold 1: Minimum of 50mm rainfall over 6 weeks before planting;
- Threshold 2: Minimum of 10mm of rainfall per dekad during growing season (June to August);
- Threshold 3: Minimum of 10mm of rainfall per week during September)

The model produced fairly accurate yield predictions in Area 2, the inland Swartland region. Of the eleven years tested, ten were correctly or marginally correctly predicted. These results are encouraging, as they not only provide a simplistic model for farmers to use, as an estimator of the expected yield outcome for the season, but they also identify specific periods and rainfall characteristics, which could be further investigated. The model is ultimately a numerical quantification of the inherent knowledge of wheat farmers in the Swartland.

Although the model may not provide yield estimations in a timely manner (i.e. before the beginning of the season) for farmers, it may provide confirmation towards the latter end of the growing season of a likely yield outcome that could potentially help farmers in their decision making. For example, if a farmer were to experience unfavourable rainfall conditions during the first half of the season (threshold one not met and only one of the first five dekads of threshold two seeing sufficient rainfall) the likelihood of a poor yield would be high and so a farmer could choose to stop investing (through inputs such as fertilizer, pesticides etc.) in the crop to reduce losses. Of course, if this scenario were to occur the farmer would have already observed the impacts of the low rainfall in the wheat crop and would already be contemplating such a decision. Therefore, the model would provide confirmation and aid in the decision making process.

The inclusion of forecasted seasonal climatic information could increase the usefulness of the yield prediction model. Combining forecasted climatic information on the seasonal scale (given the forecast has adequate skill) with the yield prediction model could potentially provide very useful information to wheat farmers. This model information would influence a much wider range of production decisions. Current conventional seasonal forecasts produce information at temporal and spatial scales which are incompatible with the yield prediction model. The yield prediction model operates at the dekadal scale within a sub-region of the Swartland; however, seasonal forecasts produce climate information at a trimonthly scale for the southern African region.

The yield prediction model could also potentially be used in parallel with climate change projections to assess the effects local climate shifts, as a result of climate change, may have on the wheat production in the Swartland region.

It is worth noting that correlations between various rainfall characteristics and seasonal rainfall totals were observed; therefore, skilful forecasts of seasonal rainfall totals could potentially be used to create skilful predictions of wheat yields.

5.1.2 Limitations

As important as explaining the positive aspects of this research, it is equally important to understand the associated limitations. Large-scale ocean and atmospheric patterns, which influence rainfall, have been shown to contain decadal variability. This section of the analysis was conducted using a 17 year period, due to limitations in the available wheat yield records, which is only just over one and a half decades. This places limitations on the confidence of the statistical relationships found in this section.

The rainfall record for Area 2 was created by aggregating seven scattered weather station records. Within Area 2 many microclimates exist and so the aggregated rainfall record may not coincide with the conditions experienced at the main wheat growing farms in the area. Therefore, the rainfall record is only a proxy for the rainfall experienced by the wheat crop. Due to the nature of the climate and the varying soil types experienced throughout the Swartland the results from the model are restricted to Area 2 and cannot confidently be extrapolated to Areas 1 and 3.

High crop yields are not always synonymous with profitable financial returns for wheat farmers in the Swartland. With the free trade market in South Africa the wheat price is dependent on the international market, which fluctuates regularly. A farmer could experience a year of exceptional yield, but if the wheat price is low the financial returns may not be great and conversely a farmer may experience their most profitable year with a crop of below average yield if the wheat price is high. Therefore, although the yield related information is useful, the financial outcome is dependent on many other factors.

This part of the study has focused solely on the associated impacts of rainfall on wheat yield; however, it is not the only impacting climatic variable. Temperature also plays a major role throughout the phenological phases of the wheat plant (see Chapter 2). Due to the nature of mid-latitude systems, which bring the majority of rainfall experienced in the winter rainfall region of South Africa, rainfall is closely linked to changes in temperature and, as such, the *rainfall*-wheat yield analysis could also partly reflect the influence of temperatures. Other climatic factors such as humidity and surface wind also effect evapotranspiration and, therefore, affect the water balance of the dryland wheat crop. The effects of temperature and other climatic variables on wheat yields in Swartland could provide valuable additional information and is an aspect recommended for future studies.

The yield prediction model requires testing against a reference forecast before any degree of skill can be attributed to the model. Until the model is tested, the results and subsequent discussion could be deemed bias.

5.2 Association of climate indices with wheat yield

The objective addressed in this section of the analysis was to assess the relationships between global teleconnections that may influence climate variability in the Swartland region and wheat yields. Three teleconnections (El Niño-Southern Oscillation [ENSO], Antarctic Oscillation [AAO] and South Atlantic sea surface temperatures [SSTs]) represented by eight climate indices (**Nino3.4** Index, Ocean Nino Index [**ONI**], Southern Oscillation Index [**SOI**], **AAO** index, Southern Annular Mode Index [**SAM**], South Atlantic Dipole Index [**SADI**], South Western Atlantic SST Index [**SWAI**] and South Central Atlantic SST Index [**SCAI**]), were correlated against the wheat yield data from Area 2 over the 17 year period from 1994 to 2010.

For the AAO teleconnection indices, significant correlations were observed for **SAM** and wheat yield during JAS ($r = -0.461$, $\rho<0.1$) and OND ($r=0.480$, $\rho<0.1$) and for **AAO** and wheat yield during OND($r=0.424$, $\rho<0.1$). For the South Atlantic SST teleconnection, the **SWAI** showed one significant correlation with wheat yield, during the MJJ period ($r= -0.4932$, $\rho<0.05$). The **SCAI** showed significant correlation with wheat yield for JFM ($r=0.542$, $\rho<0.05$) and FMA ($r=0.460$, $\rho<0.1$). No significant correlations were observed between the **SADI** and wheat yield. For the ENSO teleconnection, three significant negative correlations were observed between **ONI** and wheat yields during; JFM ($r= -0.428$, $\rho<0.1$), JJA ($r= -0.430$, $\rho<0.1$) and JAS ($r= -0.426$, $\rho<0.1$). The **SOI** showing three positive significant correlations with wheat yields during; FMA ($r=0.434$, $\rho<0.1$), JJA ($r=0.556$, $\rho<0.05$) and JAS ($r=0.696$, $\rho<0.0025$). No significant correlations were observed between **Nino3.4** and wheat yield from Area 2 in the Swartland region.

With previous literature describing the effects of the three teleconnections on winter rainfall in South Africa (Reason *et al.* 2002; Reason & Jagadheesha 2005; Reason & Rouault

2005; Philippon *et al.* 2011), it was assumed that mechanisms that resulted in increased winter rainfall would also be associated with increased wheat yield in the Swartland. This assumption does hold true for most of the significant correlations (as highlighted in Chapter 4), with the exception of the ENSO indices-wheat yield correlations. The ENSO indices-wheat yield correlations suggested that years of below normal yield were associated with years that experienced warmer SSTs over the Nino3.4 region for seasonal periods throughout the year. However, as previously stated (Chapter 2), previous studies (Philippon *et al.* 2011) have shown warmer SSTs over the Nino3.4 region to be associated with wetter winters in the winter rainfall region of South Africa. Therefore, the ENSO indices-wheat yield correlations intimate that higher yields are associated with years of drier winters. This result, in isolation, is rather perplexing and counterintuitive. An assessment of the results from all three analyses sections from this study, presents a possible explanation.

Examining the *rainfall*-climate indices analysis for Area 2 (recalling the wheat yield data is only representative of Area 2) allows one to see the effects of the ENSO on the rainfall characteristics. The rainfall that occurs within Area 2 during the first half of the wheat growing season (MAM, AMJ and MJJ) is positively correlated with SSTs over the eastern equatorial Pacific during the first half of the year (January to June). Conversely, the rainfall that occurs within Area 2 during the second half of the wheat growing season (JJA, JAS and ASO) is negatively correlated with SSTs over the same eastern equatorial Pacific during the same January to June period (first half of the year).

These findings suggest warmer (cooler) SSTs in the Nino3.4 region during the first half of the year are associated with wetter (drier) than normal MAM, AMJ and MJJ and drier (wetter) than normal JJA, JAS and ASO periods in Area 2 of the Swartland region. Focusing only on the significant correlations from the *rainfall*-ENSO analysis (which predominantly occur between rainfall during the latter half of the year and ENSO during the first half of the year), they suggest that the association of ENSO is greater on rainfall during the latter half of the growing season than during the first half, in Area 2. From the *rainfall*-yield analysis the importance of the rainfall during the latter half of the wheat growing season, in determining the wheat yield, was emphasized (remembering a crop could recover from a poor rainfall during the beginning of the season, but not from poor rainfall during the latter parts of the wheat growing season). Therefore, the negative correlation between ENSO SST indices and rainfall during the latter half of the season plays a larger role in determining the wheat yield in comparison to the positive correlation between the ENSO SST indices and rainfall during the beginning half of the season. This explains the unexpected results obtained in the ENSO indices-wheat yield analysis.

5.2.1 Validation

In an attempt to validate the correlations between the three teleconnection and the wheat yield in the Swartland region, composite maps for various large-scale atmospheric fields (surface pressure, SSTs and surface wind) were analysed. These composite maps showed anomalous deviations from the climatology during extreme (greater or less than one standard deviation from the mean) wheat yield years for the winter and seasonal (early and late) time period. The composite analysis supported the correlation findings between the climate indices and wheat yield. Despite the relatively short time period of focus (17 year period), the large-scale surface and atmospheric circulation patterns associated with years that experienced extreme wheat yield are robust.

The significant correlations between the climate indices and wheat yields provide useful information regarding the state of the atmosphere and its potential influence on wheat yields experienced in Area 2 of the Swartland region. The mechanisms associated with the links between each of the three teleconnections and winter rainfall in South Africa have previously been proposed in the literature (Reason *et al.* 2002; Reason & Jagadheesha 2005; Reason & Rouault 2005; Blamey & Reason 2007; Pohl *et al.* 2010 Phillipon *et al.* 2011). However, as in the case between the ENSO indices and wheat yield, the mechanisms associated with the links between the three teleconnections and wheat yield cannot be assumed to be the same as those found between the teleconnections and winter rainfall. Without a comprehensive understanding of the dynamics of how the three teleconnections influence the local climate and, therefore, the wheat yield in the Swartland, the usefulness of the correlations between the climate indices and wheat yield is very limited.

5.2.2 Application to farmers

The climate indices-wheat yield correlations can only suggest the yield outcome of a particular year by examining the state of the atmosphere during certain periods. If you were to give a farmer only information regarding the magnitude of the expected yield for a particular year, the farmer could find the usefulness of this information very limiting. Although the farmer would have an idea of expected yield, the farmer has little information regarding the expected within-season climatic variation. Therefore, the farmer cannot implement any strategies to either, mitigate risk (if low yield was predicted), or try to capitalize on potential financial returns (if a high yield was predicted). Therefore, there is a need to examine the climate indices-rainfall relationships to provide farmers with useful information, hence the third objective of the analysis.

5.2.3 Limitations

As stated in 5.1.2 above, this section of the analysis was conducted using the available 17 year period which limits the confidence of the statistical relationships found in this section.

Large-scale surface and atmospheric dynamics are not only related to the rainfall that occurs in the Swartland, but ultimately to all climatic variables, which are experienced in the region. As explained in the previous section, a number of these variables play a role in determining the yield of the wheat crop, e.g. temperature and surface wind. For this reason it is important to emphasize that the correlations and composites analyses between the teleconnections and wheat yield may include the influences of additional climate variables, other than rainfall, on the wheat yield. Therefore, it cannot explicitly be stated that the correlations were solely related to rainfall.

5.3 Association of rainfall characteristics with climate indices

The final objective of the study was to evaluate any apparent influence large-scale modes of climate variability had on wheat-specific rainfall characteristics in the Swartland region. Three teleconnections (ENSO, AAO, South Atlantic SSTs), represented by eight climate indices (Nino3.4 Index, ONI, SOI, AAO index, SAM Index, SADI, SWAI and SCAI), were correlated against six wheat-specific rainfall characteristic indices (rainfall, wet days, 'good' rainfall, heavy rainfall, percentage 'good' rainfall and dry dekads) from each of the three study areas over the period from 1980 to 2012. The main significant correlations from the correlation analysis between the climate indices and rainfall, from the three study areas, are shown in Table 5.1.

As shown in Chapter 4, a number of the significant correlations obtained from the *rainfall*-climate indices analysis aligned well with previous studies (Reason *et al.* 2002; Reason & Jagadheesha 2005; Reason & Rouault 2005; Phillipon *et al.* 2011). From the five additional rainfall characteristic indices (*wet days, 'good' rainfall, heavy rainfall, percentage 'good' rainfall* and *dry dekads*)-climate indices correlation analysis, correlation patterns between the teleconnections and rainfall characteristics were similar to those observed in the *rainfall*-climate indices analysis. An interesting finding to emerge from this section of the analysis was, the varying influence teleconnections had on the three study areas. The rainfall characteristics from Areas 2 and 3 were generally influenced in the same manner by each of the three teleconnections and over similar periods. The rainfall characteristics from Area 1 on the other hand, showed generally fewer correlations with the teleconnections and at times, displayed correlations contradictory to those observed in Areas 2 and 3.

Table 5.1: Summary of the significant correlations obtained from the correlation analysis between the climate indices and *rainfall* from the three study areas.

Correlation Analysis	**Area 1 (Northern extent)**	**Area 2 (Eastern, inland)**	**Area 3 (Western, Coastal)**
ENSO-*rainfall*	• Few significant correlations. • The **ONI** and **SOI**-*rainfall* correlations contradicted those in Areas 2 and 3.	• Positive correlations (negative for **SOI**) between *rainfall* during AMJ and ENSO indices during the AMJ and MAM. • Negative correlations (positive for **SOI**) between *rainfall* during the latter half of winter season (JAS, ASO and SON) and ENSO indices during the beginning half of the year (JFM to JJA).	• Positive correlations (negative for **SOI**) between *rainfall* during the first half of the wheat growing season (MAM to JJA) and ENSO indices over the beginning half of the year (JFM to JJA). • Negative correlations (positive for **SOI**) between *rainfall* during the latter half of winter season (JAS, ASO and SON) and ENSO indices during the beginning half of the year (JFM to AMJ).
AAO-*rainfall*	• Only one significant correlation between *rainfall* and the **AAO** index (SON *rainfall*-JAS **AAO**). • Negative significant correlations between *rainfall* during JAS and **SAM** during JFM to MAM. • Two positive correlations between *rainfall* during the AMJ and JJA periods and **SAM** over the same periods, respectively.	• Only negative significant correlations between the AAO indices and *rainfall*. • Strong correlations between *rainfall* during JJA and the AAO indices during MAM to MJJ.	• Only negative significant correlations between the AAO indices and *rainfall*. • Strong correlations between *rainfall* during JJA and the AAO indices during AMJ and MJJ.
South Atlantic SST-*rainfall*	• No significant correlations between **SWAI** and *rainfall*. • Negative significant correlations between **SCAI** (during MAM to ASO) and late seasonal *rainfall* (JAS to SON). • **SADI** a weaker, inverse reflection of **SCAI** (due to lack of significant SWAI-*rainfall* correlations).	• Two significant positive correlations between **SWAI** and *rainfall* (SON *rainfall*-FMA and MAM **SWAI**). • Negative significant correlations between **SCAI** (during MAM to ASO) and late seasonal *rainfall* (JJA to ASO). • **SADI** a weaker, inverse reflection of **SCAI** (due to lack of significant SWAI-*rainfall* correlations).	• A two significant positive correlations between **SWAI** and *rainfall* (SON *rainfall*-FMA SWAI; OND *rainfall*-MAM SWAI) • Negative significant correlations between **SCAI** (during MAM to ASO) and late seasonal *rainfall* (JAS to ASO). • **SADI** a weaker, inverse reflection of **SCAI** (due to lack of significant SWAI-*rainfall* correlations).

5.3.1 Validation

In an attempt to validate the correlations between the three teleconnection and the *rainfall* index, composite maps for various large-scale atmospheric fields (SSTs and geopotential height [700mb]) were analysed. Two significant correlations from each of the three teleconnection-*rainfall* analyses were verified using composite maps to confirm the existence of the relationships between the *rainfall* and the large-scale modes of variability. These composite maps showed the anomalous deviations from the climatology during anomalously (greater or less than half a standard deviation from the mean) wet and dry years for certain time periods. The composite analysis supported the significant correlations observed between the climate indices and the *rainfall* index.

The correlation and composite validation analyses successfully evaluated any apparent influence large-scale modes of climate variability had on wheat-specific rainfall characteristics in the Swartland region. The significant correlations between the three teleconnections and the rainfall characteristics for each area were tallied using a weighting system to gauge the concentration of the relationships and is discussed in next section of this chapter (5.4).

5.3.2 Limitations

Previous literature (Reason *et al.* 2002; Reason & Jagadheesha 2005; Reason & Rouault 2005; Blamey & Reason 2007; Pohl *et al.* 2010; Phillipon *et al.* 2011) has debated the nature of the relationship between each of the three teleconnections and winter rainfall in South Western Cape (winter rainfall region). All three teleconnections have been argued to be drivers of winter rainfall variability in South Africa; however, more recent studies have suggested some teleconnections may be linked, such as the AAO and ENSO. The ENSO influence on AAO during austral summer has been shown to significantly strengthen the results of the AAO-summer rainfall analyses at the interannual time scale in South Africa (Pohl *et al.* 2010). This study does not contribute to this particular academic debate as the associations between the three teleconnections and rainfall characteristics are only used to assess the potential predictability of rainfall characteristics in the Swartland. The results from the correlation analysis of this study suggest the idea of using teleconnections to forecast rainfall characteristics is a plausible one.

This study did not attempt to investigate the exact sequencing of the mechanisms associated with the relationships found between the rainfall characteristics in the Swartland region and the teleconnections; it only quantified how strong these relationships were. The correlation results do not distinguish cause and effect relationships and no assumptions have been made in this regard about any of the relationships between the teleconnections and rainfall characteristics from the three areas.

5.4 Summary of practical uses of the research for cropping decisions and recommendations for future work

In order to assess whether any messages can be collectively drawn from this study, one needs to identify a thread of commonality between all the analyses. Area 2 is one such thread. The results from the correlation summation table, for Area 2, suggest information regarding rainfall characteristics during the latter half of the wheat growing season (JJA, JAS, ASO and SON) could potentially be acquired in advance, by examining the state of the teleconnections earlier in the year. From assessing the state of ENSO and AAO during the February to April period, one could glean information regarding the expected rainfall characteristics during July to September in Area 2. The Nino3.4 and ONI indices during FMA showed negative correlation with *rainfall*, *wet days*, '*good' rainfall* and *percentage 'good' rainfall* during the July to September period. The AAO and SAM indices during the February to April period were positively correlated with the number of *dry dekads* during JAS. Therefore, if all four climate indices were positive (negative) during the February to April period one could expect the July to September period to experience less (increased) rainfall as a result of fewer (more) wet days, with even fewer (more) 'good' rainfall events, and an increased (decreased) chance of experiencing dry dekads. This information is available prior to planting which occurs during mid-May to early June. The importance of this rainfall in determining the wheat yield in Area 2 has already been established (objective one). This forecasted rainfall information could be incorporated in the yield prediction model to assess the expected yield for a particular year in Area 2. For example, decisions regarding; the amount of land to cultivate; the choice of crop; crop management (how much inputs to invest); crop insurance; the selling of the wheat crop (occurs during the season) etc.

The earlier tailored forecast information can get to wheat farmers the greater the potential benefit for the farmer; however, the forecast information would still be of use to farmers if it was received half way through the growing season. There is the potential of using Global Climate Models (GCMs) to predict large-scale modes at the seasonal scale. The forecasted states of the teleconnections could then be used to statistically infer attributes of the rainfall and yield, therefore, providing information to the farmer much earlier. Further investigation is needed to assess on what time frames information can be acquired and the usefulness of this information for the farmers.

The limitations of using seasonal rainfall totals to predict wheat yields supports the current lack of uptake of seasonal forecasts amongst farmers, as the information supplied is not skilful. Despite the extensively documented potential benefits seasonal forecasting could provide to the agricultural sector (Cane *et al.* 1994; Klopper & Bartman 2003; Johnston *et al.*

2004), the skill and relevance of seasonal rainfall totals are two of the factors constraining these benefits from reaching the farmers.

Recommendations for future studies include the creation and validation of a statistical forecast model combining the knowledge of the teleconnection (climate indices)-rainfall characteristics-wheat yield relationships and the yield prediction model from this study. The climatic and yield related information from this statistical forecast model could be packaged within an advisory and disseminated to wheat farmers in the Swartland. A statistical method that can handle multidimensional datasets is required to develop the forecast model. The multiple regression econometric analysis technique, known as Panel Data Analysis, could be an appropriate method.

It is recommended that future studies investigate the possibility of increasing the resolution to the individual weather station/farm scale. The benefits of this modification are threefold. Individual weather stations would be better suited in identifying the different responses of local climate to large-scale forcing that exist within the Swartland region. Farms typically keep detailed records of wheat production and many of these would exceed the length of the farming co-operative's records and, therefore, allow for a more comprehensive analysis. This increase in resolution would also allow for the study to examine the dynamics of the rainfall (and associated teleconnections) with wheat yields across the entire Swartland region.

Broadening the scope of the study to include additional local climatic factors (such as temperature, surface wind, humidity etc.), that influence wheat yields, in addition to the inclusion of more teleconnections (more ENSO, AAO and South Atlantic SST indices as well as an Antarctic sea ice index etc.) would increase the robustness of any future studies. This increase in scope increases the probability of identifying a greater number of mechanisms by which; the large-scale atmospheric dynamics influence the local climate factors; and the local climate influences the wheat yield. This would increase the reliability, usefulness, skill and accuracy of any information or forecast model to emerge from the analysis, which would be of greater benefit to wheat farmers. The methodology followed in this study could easily be adapted to focus on an alternative crop, as long as the crop shows a significant dependence on the environmental conditions experienced throughout the season.

The study illustrates the usefulness of active communication with users (in this case, farmers) in order to produce climate related information that is user-focused and decision relevant. This study has explicitly shown evidence supporting the plausibility and validity of the use of the state of large-scale modes of variability in the prediction of wheat-specific rainfall characteristics and aggregated yields across a wide region. This could provide wheat farmers in the Swartland with useful information to aid in the decision making process. It is hoped that this may contribute to a financially viable wheat production industry, which is beneficial to not only the South African economy, but also helps to provide food security to a rapidly expanding nation.

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APPENDIX

Appendix A

Pearson's correlation coefficients obtained from comparing total *rainfall* Index over the 1980-2012 period from each of the three study areas with:

A-1) three El Niño-Southern Oscillation (ENSO) indices;

A-2) two Antarctic Oscillation (AAO) indices;

A-3) three South Atlantic sea surface temperature (SST) indices.

Highlighted coefficients are significant at the 10% significance level with darker shadings indicating greater significance (see key).

Appendix A Key			
ρ value	**Value**		**Significance**
	Negative	Positive	
0.1	-0.2913	0.2913	10.00%
0.05	-0.3440	0.3440	5.00%
0.025	-0.4032	0.4032	2.00%
0.01	-0.4421	0.4421	1.00%
0.005	-0.4770	0.4770	0.50%
0.0025	-0.5184	0.5184	0.20%
0.001	-0.5465	0.5465	0.10%

ENSO		Area 1 RAINFALL												Area 2 RAINFALL				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
NINO3.4	JFM	-0.01	0.02	-0.13	0.08	0.09	0.10	-0.11	-0.31	-0.11	-0.10	-0.03	-0.08	-0.18	-0.12	0.07	0.21	0.06
	FMA		0.30	0.13	0.10	-0.07	-0.11	-0.19	-0.30	-0.29	-0.18	-0.19	-0.03		-0.13	0.10	0.25	0.10
	MAM			0.07	-0.14	-0.25	-0.24	-0.10	0.02	0.01	0.04	-0.06	0.10			0.10	0.31	0.18
	AMJ				-0.18	-0.18	-0.30	-0.05	0.03	0.06	0.15	0.14	0.15				0.32	0.24
	MJJ					-0.01	-0.22	-0.06	-0.03	0.06	0.07	0.16	-0.01					0.21
	JJA						-0.18	-0.12	-0.23	-0.25	-0.18	-0.06	-0.14					
	JAS							-0.17	-0.27	-0.46	-0.36	-0.32	-0.14					
	ASO								-0.17	-0.20	-0.15	-0.16	-0.01					
	SON									-0.03	-0.08	-0.08	0.11					
	OND										-0.08	0.01	0.02					
	NDJ											-0.04	-0.01					
	DJF												0.02					
ONI	JFM	0.12	0.02	-0.11	-0.12	0.03	0.23	0.28	0.18	0.22	0.01	0.12	0.06	-0.19	-0.10	0.09	0.24	0.06
	FMA		0.05	-0.07	-0.14	0.02	0.15	0.24	0.16	0.23	0.05	0.12	0.08		-0.11	0.10	0.27	0.09
	MAM			0.02	-0.17	-0.17	-0.07	0.15	0.15	0.14	-0.04	0.03	0.02			0.08	0.31	0.15
	AMJ				-0.22	-0.14	-0.10	0.19	0.20	0.24	0.06	0.16	0.06				0.31	0.20
	MJJ					-0.19	-0.13	0.15	0.24	0.24	0.15	0.21	0.10					0.19
	JJA						-0.07	0.23	0.29	0.30	0.22	0.30	0.18					
	JAS							0.17	0.27	0.25	0.20	0.24	0.16					
	ASO								0.26	0.19	0.08	0.15	0.10					
	SON									0.13	-0.03	0.09	0.09					
	OND										-0.06	0.11	0.10					
	NDJ											0.13	0.12					
	DJF												0.21					
SOI	JFM	-0.15	-0.09	0.08	0.12	-0.05	-0.25	-0.35	-0.19	-0.19	0.15	-0.05	0.06	0.10	0.00	-0.14	-0.26	-0.09
	FMA		-0.07	0.12	0.18	0.01	-0.24	-0.37	-0.23	-0.20	0.13	-0.08	0.01		0.08	-0.05	-0.24	-0.08
	MAM			0.15	0.27	0.11	-0.15	-0.38	-0.28	-0.20	0.12	-0.09	-0.09			0.12	-0.18	-0.17
	AMJ				0.34	0.22	0.01	-0.32	-0.29	-0.17	0.10	-0.08	-0.19				-0.12	-0.07
	MJJ					0.26	0.17	-0.21	-0.22	-0.13	0.05	-0.07	-0.23					-0.11
	JJA						0.25	-0.10	-0.14	-0.11	-0.02	-0.07	-0.23					
	JAS							-0.05	-0.09	-0.12	-0.08	-0.08	-0.22					
	ASO								-0.09	-0.12	-0.10	-0.08	-0.21					
	SON									-0.12	-0.10	-0.07	-0.21					
	OND										-0.08	-0.06	-0.22					
	NDJ											-0.08	-0.23					
	DJF												-0.24					

Area 2 RAINFALL							Area 3 RAINFALL											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.17	-0.36	-0.26	-0.25	0.16	-0.02	0.09	-0.06	-0.04	0.23	0.32	0.22	-0.06	-0.34	-0.27	-0.28	0.11	-0.09	-0.04
-0.18	-0.38	-0.30	-0.27	0.15	-0.03	0.05		-0.05	0.27	0.40	0.29	-0.04	-0.35	-0.31	-0.29	0.11	-0.08	-0.05
-0.13	-0.39	-0.38	-0.28	0.11	-0.05	-0.02			0.27	0.50	0.40	0.05	-0.36	-0.37	-0.31	0.10	-0.07	-0.11
0.00	-0.33	-0.40	-0.26	0.07	-0.05	-0.09				0.52	0.46	0.19	-0.28	-0.35	-0.27	0.10	-0.01	-0.12
0.12	-0.18	-0.27	-0.20	0.00	-0.07	-0.13					0.40	0.30	-0.12	-0.19	-0.17	0.08	0.01	-0.12
0.19	-0.05	-0.13	-0.14	-0.05	-0.08	-0.14						0.36	0.01	-0.04	-0.09	0.05	0.03	-0.09
	-0.02	-0.07	-0.13	-0.09	-0.10	-0.15							0.06	0.03	-0.06	0.04	0.02	-0.10
		-0.08	-0.14	-0.12	-0.13	-0.18								0.01	-0.08	0.00	0.00	-0.13
			-0.13	-0.10	-0.13	-0.20									-0.07	0.01	0.01	-0.14
				-0.07	-0.13	-0.21										0.02	0.01	-0.14
					-0.13	-0.19											0.00	-0.13
						-0.20												-0.13
-0.17	-0.38	-0.27	-0.28	0.17	-0.02	0.10	-0.08	-0.02	0.24	0.35	0.23	-0.04	-0.35	-0.28	-0.29	0.13	-0.08	-0.02
-0.17	-0.41	-0.32	-0.31	0.14	-0.05	0.05		-0.04	0.26	0.42	0.30	-0.01	-0.37	-0.32	-0.31	0.12	-0.09	-0.06
-0.14	-0.43	-0.39	-0.31	0.12	-0.07	-0.02			0.24	0.49	0.39	0.06	-0.38	-0.37	-0.30	0.12	-0.09	-0.11
-0.05	-0.38	-0.39	-0.27	0.09	-0.07	-0.10				0.52	0.45	0.17	-0.33	-0.35	-0.25	0.14	-0.04	-0.15
0.05	-0.26	-0.30	-0.20	0.05	-0.07	-0.13					0.42	0.25	-0.20	-0.23	-0.16	0.14	0.00	-0.14
0.12	-0.13	-0.18	-0.16	-0.02	-0.09	-0.14						0.30	-0.07	-0.08	-0.09	0.10	0.01	-0.11
	-0.06	-0.10	-0.14	-0.07	-0.12	-0.16							0.02	0.00	-0.07	0.06	0.00	-0.10
		-0.07	-0.13	-0.09	-0.13	-0.17								0.02	-0.07	0.03	0.01	-0.10
			-0.12	-0.09	-0.13	-0.18									-0.06	0.03	0.01	-0.11
				-0.07	-0.13	-0.19										0.04	0.01	-0.12
					-0.15	-0.20											-0.02	-0.13
						-0.21												-0.15
0.13	0.30	0.27	0.31	0.04	0.14	0.09	-0.02	-0.08	-0.31	-0.39	-0.27	0.02	0.28	0.28	0.30	0.06	0.21	0.22
0.07	0.27	0.25	0.33	0.06	0.12	0.08		-0.02	-0.26	-0.42	-0.30	-0.08	0.24	0.27	0.34	0.08	0.17	0.20
-0.07	0.17	0.20	0.22	-0.04	0.02	-0.01			-0.09	-0.38	-0.40	-0.23	0.14	0.21	0.23	-0.02	0.04	0.13
-0.07	0.20	0.19	0.30	0.01	0.10	-0.05				-0.32	-0.30	-0.27	0.12	0.15	0.30	0.02	0.09	0.04
-0.10	0.13	0.16	0.25	0.09	0.17	0.02					-0.26	-0.25	0.07	0.10	0.26	0.08	0.12	0.02
-0.04	0.20	0.23	0.30	0.16	0.24	0.10						-0.26	0.09	0.13	0.29	0.11	0.17	0.04
	0.15	0.21	0.25	0.13	0.19	0.07							0.05	0.12	0.24	0.09	0.10	0.01
		0.21	0.18	0.05	0.15	0.04								0.13	0.18	0.00	0.05	-0.01
			0.15	-0.03	0.13	0.04									0.11	-0.10	0.03	0.00
				-0.05	0.13	0.00										-0.11	0.05	-0.03
					0.14	0.02											0.07	0.00
						0.08												0.06

AAO		Area 1 RAINFALL												Area 2 RAINFALL				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
AAO	JFM	-0.07	-0.04	-0.16	-0.02	0.05	0.09	0.03	-0.13	0.04	-0.09	-0.08	-0.06	-0.12	-0.04	-0.21	-0.11	-0.10
	FMA		0.11	0.12	0.00	-0.08	-0.20	-0.10	-0.18	-0.11	-0.11	-0.13	0.09		0.05	0.10	-0.02	-0.14
	MAM			0.04	-0.09	-0.20	-0.25	-0.12	-0.02	0.04	0.01	-0.05	0.10			-0.01	-0.22	-0.32
	AMJ				-0.12	-0.16	-0.27	-0.03	0.00	0.02	0.06	0.09	0.16				-0.27	-0.27
	MJJ					-0.10	-0.26	-0.04	0.00	-0.02	-0.06	0.00	-0.02					-0.25
	JJA						-0.23	-0.08	-0.13	-0.16	-0.14	-0.09	-0.04					
	JAS							-0.10	-0.20	-0.31	-0.24	-0.27	-0.02					
	ASO								-0.23	-0.22	-0.10	-0.09	0.10					
	SON									-0.10	-0.10	-0.12	0.18					
	OND										-0.12	-0.02	0.07					
	NDJ											-0.08	0.09					
	DJF												0.06					
SAM	JFM	-0.14	-0.11	0.07	0.09	-0.05	-0.26	-0.34	-0.18	-0.16	0.14	-0.04	0.05	-0.14	-0.04	-0.25	-0.05	-0.09
	FMA		-0.09	0.12	0.16	0.00	-0.25	-0.35	-0.22	-0.17	0.13	-0.05	0.02		0.21	0.10	0.09	-0.13
	MAM			0.16	0.27	0.13	-0.15	-0.35	-0.29	-0.19	0.11	-0.06	-0.07			0.00	-0.27	-0.36
	AMJ				0.36	0.25	0.05	-0.28	-0.31	-0.20	0.06	-0.06	-0.18				-0.28	-0.26
	MJJ					0.27	0.23	-0.14	-0.21	-0.14	0.00	-0.06	-0.22					-0.17
	JJA						0.33	-0.03	-0.11	-0.11	-0.05	-0.06	-0.22					
	JAS							-0.01	-0.08	-0.10	-0.09	-0.06	-0.22					
	ASO								-0.10	-0.12	-0.13	-0.07	-0.22					
	SON									-0.12	-0.12	-0.07	-0.23					
	OND										-0.09	-0.07	-0.25					
	NDJ											-0.07	-0.23					
	DJF												-0.23					

Area 2 RAINFALL							**Area 3 RAINFALL**											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
0.00	0.00	-0.08	0.05	-0.02	-0.06	-0.01	-0.17	-0.16	-0.33	-0.13	-0.09	0.00	0.00	-0.10	0.08	-0.13	-0.16	-0.18
-0.20	-0.13	-0.14	-0.23	-0.11	-0.21	0.04		-0.05	0.00	0.02	-0.03	-0.07	-0.06	-0.14	-0.19	-0.25	-0.28	-0.11
-0.35	-0.17	-0.02	-0.09	0.02	-0.09	0.08			-0.09	-0.15	-0.17	-0.17	-0.08	0.01	-0.05	-0.10	-0.19	-0.05
-0.38	-0.08	0.01	0.00	0.12	0.08	0.13				-0.24	-0.17	-0.23	0.02	0.04	0.00	0.02	0.01	0.08
-0.38	-0.07	0.01	-0.01	-0.06	-0.06	-0.14					-0.20	-0.30	-0.01	0.03	0.02	-0.07	-0.08	-0.14
-0.28	-0.10	-0.12	-0.20	-0.21	-0.20	-0.25						-0.15	-0.01	-0.07	-0.12	-0.18	-0.17	-0.22
	-0.10	-0.17	-0.43	-0.35	-0.39	-0.21							0.01	-0.09	-0.29	-0.33	-0.35	-0.22
		-0.26	-0.35	-0.19	-0.16	-0.01								-0.14	-0.25	-0.23	-0.12	0.01
			-0.18	-0.13	-0.16	0.08									-0.11	-0.18	-0.16	0.07
				-0.13	-0.02	0.02										-0.16	0.00	0.02
					-0.07	0.03											-0.04	0.01
						0.05												0.11
-0.02	-0.14	-0.26	-0.04	-0.02	-0.02	-0.04	-0.20	-0.13	-0.32	-0.05	-0.09	-0.06	-0.17	-0.32	-0.10	-0.19	-0.15	-0.21
-0.12	-0.21	-0.25	-0.31	-0.17	-0.23	-0.06		0.11	0.05	0.09	-0.09	-0.10	-0.19	-0.28	-0.36	-0.35	-0.31	-0.16
-0.34	-0.15	0.04	-0.08	0.05	-0.09	0.10			-0.06	-0.20	-0.25	-0.21	-0.07	0.06	-0.06	-0.10	-0.20	-0.01
-0.40	-0.10	0.02	0.09	0.25	0.22	0.20				-0.30	-0.25	-0.35	-0.02	0.08	0.10	0.16	0.14	0.11
-0.39	-0.10	-0.04	0.11	0.10	0.14	-0.09					-0.16	-0.35	-0.04	0.01	0.15	0.10	0.11	-0.14
-0.25	-0.16	-0.23	-0.25	-0.18	-0.08	-0.27						-0.11	-0.06	-0.15	-0.19	-0.14	-0.02	-0.26
	-0.17	-0.25	-0.58	-0.39	-0.37	-0.23							-0.01	-0.15	-0.46	-0.38	-0.32	-0.25
		-0.23	-0.35	-0.20	-0.17	-0.05								-0.11	-0.24	-0.23	-0.17	-0.09
			-0.14	-0.13	-0.12	0.02									-0.06	-0.17	-0.15	-0.01
				-0.14	-0.03	-0.08										-0.19	-0.03	-0.11
					-0.05	-0.09											-0.04	-0.13
						0.02												0.08

S. Atlantic SSTs		Area 1 RAINFALL												Area 2 RAINFALL				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
SADI	JFM	0.08	0.00	0.06	-0.01	-0.09	-0.20	-0.15	0.14	0.12	0.26	0.00	0.10	0.11	-0.02	0.17	0.16	0.09
	FMA		0.01	-0.07	-0.08	-0.09	-0.11	-0.06	0.16	0.15	0.24	-0.06	0.06		0.06	0.05	0.10	0.08
	MAM			-0.28	-0.18	-0.11	-0.02	0.02	0.19	0.23	0.26	0.03	0.00			-0.19	-0.03	-0.01
	AMJ				-0.32	-0.12	0.12	0.18	0.25	0.22	0.21	0.12	0.02				-0.20	-0.06
	MJJ					-0.11	0.17	0.33	0.25	0.19	0.11	0.19	0.04					-0.06
	JJA						0.19	0.47	0.29	0.15	0.02	0.14	0.10					
	JAS							0.49	0.32	0.13	0.00	0.10	0.20					
	ASO								0.36	0.17	0.10	0.16	0.31					
	SON									0.13	0.09	0.14	0.32					
	OND										0.06	0.04	0.06					
	NDJ											-0.13	-0.18					
	DJF												-0.27					
SWAI	JFM	-0.05	0.01	-0.01	0.03	-0.03	-0.06	-0.07	0.04	0.17	0.18	0.11	-0.08	0.11	0.02	0.12	0.18	0.13
	FMA		0.05	-0.09	0.01	0.03	0.07	0.01	0.01	0.18	0.21	0.09	-0.09		0.10	0.03	0.14	0.17
	MAM			-0.19	0.03	0.03	0.16	-0.04	-0.07	0.16	0.24	0.17	-0.13			-0.17	0.05	0.05
	AMJ				-0.05	0.00	0.21	0.00	-0.04	0.09	0.21	0.23	-0.11				-0.09	-0.05
	MJJ					-0.09	0.14	0.02	-0.05	0.01	0.09	0.25	-0.16					-0.17
	JJA						0.09	0.15	0.02	-0.03	-0.01	0.17	-0.13					
	JAS							0.18	0.03	-0.13	-0.12	0.04	-0.06					
	ASO								0.16	-0.06	0.04	0.17	0.17					
	SON									0.04	0.08	0.21	0.26					
	OND										0.15	0.25	0.13					
	NDJ											0.04	-0.09					
	DJF												-0.19					
SCAI	JFM	-0.13	0.01	-0.08	0.04	0.09	0.20	0.13	-0.13	-0.02	-0.18	0.09	-0.18	-0.04	0.04	-0.11	-0.06	-0.01
	FMA		0.03	0.02	0.11	0.14	0.20	0.08	-0.20	-0.04	-0.13	0.14	-0.15		0.01	-0.04	-0.01	0.03
	MAM			0.18	0.25	0.16	0.16	-0.06	-0.29	-0.15	-0.12	0.11	-0.11			0.09	0.09	0.05
	AMJ				0.38	0.16	0.05	-0.24	-0.36	-0.19	-0.06	0.06	-0.13				0.18	0.04
	MJJ					0.05	-0.09	-0.42	-0.37	-0.23	-0.05	-0.02	-0.21					-0.07
	JJA						-0.18	-0.49	-0.38	-0.24	-0.04	-0.03	-0.25					
	JAS							-0.51	-0.40	-0.30	-0.11	-0.09	-0.34					
	ASO								-0.38	-0.29	-0.13	-0.10	-0.31					
	SON									-0.16	-0.07	-0.03	-0.27					
	OND										0.04	0.14	-0.04					
	NDJ											0.21	0.12					
	DJF												0.19					

Area 2 RAINFALL							Area 3 RAINFALL											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.14	-0.17	0.06	0.00	0.13	-0.03	0.10	0.11	0.04	0.24	0.24	0.16	-0.07	-0.13	0.15	0.11	0.25	-0.06	0.11
0.00	-0.06	0.15	0.12	0.16	-0.04	0.08		0.09	0.14	0.15	0.11	0.04	-0.02	0.25	0.17	0.29	-0.02	0.15
0.04	-0.03	0.19	0.24	0.24	0.08	0.05			-0.10	0.03	0.01	0.08	-0.01	0.25	0.22	0.33	0.14	0.14
0.14	0.12	0.25	0.27	0.23	0.18	0.06				-0.14	-0.04	0.15	0.11	0.28	0.22	0.27	0.24	0.13
0.20	0.28	0.26	0.22	0.14	0.23	0.05					-0.02	0.21	0.28	0.28	0.18	0.11	0.28	0.08
0.31	0.46	0.33	0.14	0.05	0.16	0.10						0.29	0.47	0.37	0.15	-0.01	0.18	0.09
	0.54	0.37	0.07	-0.05	0.06	0.15							0.54	0.42	0.13	-0.09	0.07	0.12
		0.39	0.07	-0.04	0.06	0.21								0.43	0.14	-0.06	0.07	0.20
			-0.02	-0.12	-0.02	0.18									0.09	-0.08	0.00	0.14
				-0.15	-0.10	-0.02										-0.04	-0.05	-0.05
					-0.25	-0.17											-0.17	-0.17
						-0.18												-0.13
-0.07	-0.09	-0.03	0.21	0.09	0.13	-0.07	0.01	0.04	0.13	0.14	0.04	-0.15	-0.08	0.05	0.23	0.20	0.18	0.12
0.09	0.01	0.01	0.31	0.18	0.13	-0.08		0.08	0.06	0.09	0.06	0.01	0.04	0.13	0.30	0.29	0.21	0.12
0.10	-0.08	-0.06	0.29	0.25	0.20	-0.10			-0.14	0.02	-0.03	0.05	-0.05	0.02	0.24	0.33	0.32	0.07
0.09	-0.06	-0.04	0.24	0.25	0.25	-0.06				-0.09	-0.08	0.06	-0.06	-0.01	0.17	0.28	0.34	0.04
0.03	-0.04	-0.07	0.14	0.16	0.27	-0.12					-0.13	0.04	-0.04	-0.07	0.06	0.13	0.34	-0.08
0.07	0.13	0.02	0.04	0.08	0.21	-0.08						0.08	0.13	0.03	0.01	0.01	0.22	-0.13
	0.22	0.06	-0.10	-0.07	0.06	-0.06							0.25	0.11	-0.07	-0.11	0.07	-0.13
		0.18	-0.06	-0.02	0.11	0.08								0.23	-0.02	-0.01	0.17	0.09
			-0.04	-0.08	0.08	0.11									0.03	-0.02	0.17	0.15
				-0.03	0.14	0.03										0.05	0.23	0.09
					-0.01	-0.11											0.07	-0.04
						-0.14												-0.03
0.12	0.14	-0.10	0.17	-0.09	0.14	-0.18	-0.12	-0.02	-0.19	-0.18	-0.16	-0.03	0.10	-0.14	0.05	-0.14	0.22	-0.04
0.08	0.09	-0.19	0.10	-0.06	0.16	-0.16		-0.05	-0.13	-0.13	-0.09	-0.05	0.06	-0.21	0.03	-0.13	0.20	-0.09
0.04	-0.03	-0.29	-0.05	-0.08	0.06	-0.15			0.01	-0.02	-0.04	-0.05	-0.03	-0.30	-0.07	-0.13	0.10	-0.12
-0.09	-0.21	-0.37	-0.12	-0.05	0.01	-0.14				0.10	-0.02	-0.13	-0.20	-0.37	-0.12	-0.07	0.02	-0.13
-0.24	-0.40	-0.40	-0.16	-0.03	-0.05	-0.18					-0.09	-0.24	-0.41	-0.43	-0.17	-0.02	-0.05	-0.18
-0.36	-0.51	-0.43	-0.15	0.02	-0.02	-0.21						-0.31	-0.51	-0.47	-0.19	0.03	-0.04	-0.24
	-0.53	-0.45	-0.19	0.01	-0.03	-0.27							-0.51	-0.48	-0.24	0.03	-0.02	-0.28
		-0.40	-0.16	0.04	0.00	-0.23								-0.40	-0.22	0.07	0.03	-0.21
			-0.01	0.10	0.10	-0.18									-0.11	0.10	0.14	-0.09
				0.19	0.27	0.02										0.11	0.28	0.13
					0.31	0.10											0.29	0.18
						0.11												0.14

Appendix B

Pearson’s correlation coefficients obtained from comparing three ENSO indices with wheat-specific rainfall characteristic indices over the 1980-2012 period from the three study areas.

B-1) *Wet days* index (number of days to receive >2mm);

B-2) ‘G*ood’ rainfall* index (number of days to receive >10mm);

B-3) *Percentage ‘good’ rainfall* index (ratio of ‘good’ rainfall events to *wet days*);

B-4) *Heavy rainfall* index (number of days to receive >25mm);

B-5) *Dry Dekads* index (number of dekads [10 days] to receive <10mm)

Highlighted coefficients are significant at the 10% significance level with darker shadings indicating greater significance (see key).

Appendix B Key			
ρ value	**Value**		**Significance**
	Negative	Positive	
0.1	-0.2913	0.2913	10.00%
0.05	-0.3440	0.3440	5.00%
0.025	-0.4032	0.4032	2.00%
0.01	-0.4421	0.4421	1.00%
0.005	-0.4770	0.4770	0.50%
0.0025	-0.5184	0.5184	0.20%
0.001	-0.5465	0.5465	0.10%

ENSO		Area 1 WETDAYS												Area 2 WETDAYS				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
NINO3.4	JFM	-0.02	-0.12	-0.28	-0.11	-0.09	0.02	-0.11	-0.26	-0.18	-0.14	-0.04	0.06	-0.10	0.05	0.07	0.26	0.00
	FMA		0.25	0.12	-0.04	-0.23	-0.15	-0.14	-0.18	-0.29	-0.13	-0.15	0.15		0.02	0.09	0.29	0.03
	MAM			0.22	-0.15	-0.22	-0.14	-0.04	0.00	-0.12	0.02	-0.11	0.16			0.08	0.34	0.11
	AMJ				-0.12	-0.06	-0.11	0.03	0.02	0.00	0.16	0.11	0.13				0.36	0.19
	MJJ					0.00	-0.11	0.02	-0.03	-0.05	0.04	0.07	-0.06					0.18
	JJA						-0.16	-0.08	-0.13	-0.21	-0.07	-0.04	-0.09					
	JAS							-0.15	-0.19	-0.44	-0.27	-0.28	-0.08					
	ASO								-0.13	-0.22	-0.12	-0.12	0.06					
	SON									-0.06	-0.16	-0.13	0.08					
	OND										-0.10	0.02	-0.03					
	NDJ											0.06	-0.05					
	DJF												0.01					
ONI	JFM	0.10	0.12	0.13	-0.02	0.07	0.17	0.17	0.05	0.09	0.04	0.18	0.24	-0.10	0.06	0.07	0.27	-0.02
	FMA		0.20	0.15	-0.08	0.04	0.11	0.16	0.05	0.10	0.08	0.18	0.23		0.04	0.09	0.32	0.03
	MAM			0.23	-0.12	-0.07	0.01	0.14	0.07	0.05	0.02	0.09	0.13			0.09	0.38	0.11
	AMJ				-0.26	-0.03	0.03	0.24	0.16	0.16	0.05	0.16	0.07				0.39	0.17
	MJJ					-0.01	0.04	0.20	0.17	0.19	0.08	0.15	-0.02					0.17
	JJA						0.05	0.23	0.23	0.28	0.18	0.26	0.04					
	JAS							0.18	0.25	0.27	0.18	0.19	-0.01					
	ASO								0.26	0.26	0.15	0.19	-0.03					
	SON									0.21	0.04	0.15	-0.02					
	OND										0.06	0.21	0.01					
	NDJ											0.23	0.01					
	DJF												0.10					
SOI	JFM	-0.08	-0.08	0.01	0.18	-0.02	-0.20	-0.28	-0.08	-0.03	0.14	-0.11	-0.14	0.04	-0.10	-0.08	-0.21	0.00
	FMA		-0.08	0.04	0.23	0.02	-0.20	-0.30	-0.12	-0.05	0.11	-0.14	-0.18		0.02	-0.01	-0.25	-0.03
	MAM			0.03	0.29	0.09	-0.16	-0.31	-0.17	-0.08	0.08	-0.15	-0.23			0.17	-0.20	-0.05
	AMJ				0.33	0.16	-0.04	-0.27	-0.20	-0.09	0.05	-0.13	-0.24				-0.13	0.09
	MJJ					0.18	0.07	-0.19	-0.17	-0.10	0.00	-0.10	-0.20					0.08
	JJA						0.14	-0.11	-0.12	-0.13	-0.07	-0.11	-0.14					
	JAS							-0.07	-0.10	-0.17	-0.12	-0.13	-0.09					
	ASO								-0.10	-0.20	-0.14	-0.13	-0.06					
	SON									-0.20	-0.14	-0.13	-0.05					
	OND										-0.13	-0.14	-0.07					
	NDJ											-0.17	-0.09					
	DJF												-0.10					

Area 2 WETDAYS							Area 3 WETDAYS											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.17	-0.33	-0.20	-0.13	0.13	-0.13	-0.15	-0.03	0.07	0.24	0.35	0.16	-0.14	-0.29	-0.14	0.01	0.24	-0.09	-0.20
-0.17	-0.34	-0.24	-0.15	0.10	-0.15	-0.18		0.07	0.27	0.39	0.20	-0.15	-0.31	-0.18	-0.01	0.24	-0.08	-0.20
-0.11	-0.35	-0.30	-0.20	0.06	-0.17	-0.24			0.24	0.42	0.27	-0.10	-0.31	-0.23	-0.04	0.22	-0.07	-0.24
0.04	-0.28	-0.30	-0.24	0.02	-0.14	-0.25				0.38	0.30	0.01	-0.28	-0.25	-0.08	0.19	-0.02	-0.21
0.17	-0.13	-0.19	-0.22	-0.05	-0.12	-0.19					0.22	0.11	-0.16	-0.16	-0.11	0.11	-0.01	-0.17
0.23	-0.02	-0.08	-0.19	-0.09	-0.09	-0.12						0.17	-0.07	-0.08	-0.12	0.04	0.01	-0.10
	0.02	-0.03	-0.20	-0.13	-0.10	-0.09							-0.04	-0.06	-0.17	-0.03	-0.01	-0.08
		-0.04	-0.22	-0.15	-0.11	-0.09								-0.08	-0.21	-0.07	-0.03	-0.07
			-0.21	-0.13	-0.11	-0.09									-0.21	-0.06	-0.03	-0.07
				-0.11	-0.12	-0.10										-0.03	-0.03	-0.08
					-0.12	-0.08											-0.05	-0.06
						-0.07												-0.04
-0.17	-0.36	-0.23	-0.16	0.12	-0.14	-0.14	-0.05	0.09	0.25	0.38	0.16	-0.13	-0.31	-0.17	-0.02	0.25	-0.07	-0.18
-0.15	-0.37	-0.27	-0.21	0.09	-0.17	-0.18		0.09	0.27	0.42	0.20	-0.14	-0.34	-0.21	-0.04	0.25	-0.08	-0.21
-0.09	-0.38	-0.33	-0.25	0.05	-0.20	-0.25			0.24	0.45	0.25	-0.11	-0.36	-0.26	-0.06	0.24	-0.08	-0.25
0.02	-0.33	-0.33	-0.26	0.01	-0.18	-0.28				0.41	0.27	-0.04	-0.34	-0.28	-0.08	0.21	-0.06	-0.26
0.11	-0.22	-0.26	-0.24	-0.04	-0.15	-0.23					0.21	0.05	-0.25	-0.22	-0.10	0.15	-0.03	-0.21
0.17	-0.10	-0.15	-0.23	-0.09	-0.13	-0.15						0.11	-0.14	-0.14	-0.14	0.06	-0.03	-0.14
	-0.03	-0.07	-0.23	-0.12	-0.12	-0.09							-0.07	-0.09	-0.19	-0.02	-0.03	-0.08
		-0.04	-0.22	-0.13	-0.11	-0.06								-0.09	-0.21	-0.05	-0.03	-0.05
			-0.21	-0.12	-0.11	-0.06									-0.21	-0.05	-0.03	-0.04
				-0.11	-0.11	-0.07										-0.04	-0.05	-0.05
					-0.14	-0.07											-0.08	-0.05
						-0.08												-0.05
0.16	0.28	0.23	0.22	0.09	0.26	0.28	0.01	-0.15	-0.25	-0.34	-0.16	0.12	0.22	0.14	0.08	0.00	0.24	0.32
0.06	0.24	0.22	0.26	0.12	0.25	0.28		-0.04	-0.17	-0.36	-0.23	0.01	0.17	0.15	0.11	-0.01	0.19	0.30
-0.01	0.21	0.17	0.20	0.07	0.17	0.20			0.04	-0.24	-0.22	-0.06	0.15	0.14	0.09	-0.07	0.08	0.25
-0.02	0.22	0.15	0.31	0.09	0.20	0.10				-0.17	-0.04	-0.02	0.24	0.21	0.26	-0.01	0.09	0.15
-0.02	0.16	0.08	0.27	0.11	0.19	0.00					0.05	0.03	0.24	0.17	0.27	0.06	0.11	0.05
-0.04	0.18	0.16	0.38	0.21	0.26	0.04						0.00	0.24	0.23	0.40	0.18	0.18	0.03
	0.12	0.17	0.36	0.21	0.22	0.03							0.14	0.19	0.35	0.15	0.12	-0.02
		0.18	0.30	0.13	0.18	-0.02								0.24	0.33	0.09	0.09	-0.05
			0.25	0.05	0.14	-0.02									0.28	0.00	0.08	-0.04
				0.09	0.20	-0.04										0.05	0.15	-0.06
					0.17	-0.08											0.15	-0.09
						0.01												0.00

ENSO		Area 1 GOOD RAINFALL												Area 2 GOOD RAINFALL				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
NINO3.4	JFM	-0.03	0.00	-0.20	-0.01	-0.04	-0.03	-0.16	-0.24	0.08	0.03	0.07	-0.17	-0.21	-0.30	-0.02	0.02	-0.03
	FMA		0.19	0.00	-0.07	-0.20	-0.18	-0.20	-0.21	-0.10	-0.10	-0.06	-0.17		-0.34	0.00	0.06	0.00
	MAM			0.04	-0.21	-0.30	-0.30	-0.11	0.01	0.09	0.11	0.06	0.04			-0.02	0.09	0.08
	AMJ				-0.32	-0.33	-0.41	-0.10	-0.10	-0.06	0.07	0.11	0.14				0.08	0.13
	MJJ					-0.12	-0.30	-0.12	-0.16	-0.01	0.01	0.15	0.03					0.12
	JJA						-0.24	-0.14	-0.36	-0.27	-0.24	-0.08	-0.15					
	JAS							-0.17	-0.33	-0.32	-0.26	-0.16	-0.08					
	ASO								-0.29	-0.14	-0.05	-0.05	0.07					
	SON									-0.09	0.06	0.08	0.26					
	OND										0.00	0.07	0.18					
	NDJ											-0.05	0.11					
	DJF												0.00					
ONI	JFM	0.09	0.07	-0.11	-0.06	0.06	0.15	0.28	0.20	0.31	0.06	0.00	-0.13	-0.21	-0.29	0.00	0.05	-0.01
	FMA		0.07	-0.08	-0.08	0.03	0.06	0.20	0.14	0.32	0.09	0.03	-0.11		-0.32	0.00	0.08	0.01
	MAM			-0.03	-0.10	-0.15	-0.11	0.04	0.12	0.19	-0.02	-0.02	-0.07			-0.02	0.10	0.06
	AMJ				-0.06	-0.13	-0.14	-0.01	0.11	0.24	0.10	0.20	0.04				0.10	0.11
	MJJ					-0.18	-0.14	-0.01	0.18	0.20	0.19	0.31	0.17					0.12
	JJA						-0.08	0.10	0.25	0.22	0.21	0.35	0.25					
	JAS							0.07	0.21	0.13	0.16	0.31	0.25					
	ASO								0.17	0.06	0.04	0.18	0.17					
	SON									0.03	-0.03	0.11	0.17					
	OND										-0.12	0.06	0.17					
	NDJ											0.05	0.23					
	DJF												0.29					
SOI	JFM	-0.08	-0.19	0.07	0.01	-0.05	-0.14	-0.25	-0.18	-0.35	-0.03	-0.04	0.20	0.14	0.18	-0.02	-0.02	0.03
	FMA		-0.17	0.11	0.06	0.01	-0.12	-0.26	-0.20	-0.33	-0.02	-0.07	0.13		0.25	0.08	0.02	0.06
	MAM			0.14	0.15	0.12	-0.04	-0.24	-0.24	-0.30	-0.01	-0.11	0.01			0.21	0.04	-0.07
	AMJ				0.23	0.25	0.10	-0.18	-0.27	-0.24	0.00	-0.14	-0.14				0.04	-0.03
	MJJ					0.31	0.21	-0.09	-0.24	-0.16	-0.01	-0.15	-0.25					-0.10
	JJA						0.26	-0.01	-0.18	-0.11	-0.04	-0.14	-0.29					
	JAS							0.03	-0.15	-0.08	-0.07	-0.13	-0.31					
	ASO								-0.14	-0.06	-0.09	-0.11	-0.32					
	SON									-0.04	-0.09	-0.10	-0.32					
	OND										-0.07	-0.09	-0.33					
	NDJ											-0.08	-0.33					
	DJF												-0.34					

Area 2 GOOD RAINFALL							Area 3 GOOD RAINFALL											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.23	-0.33	-0.33	-0.40	0.04	-0.04	0.10	-0.15	-0.21	0.24	0.31	0.28	0.06	-0.21	-0.22	-0.42	-0.08	-0.10	0.27
-0.25	-0.36	-0.38	-0.42	0.04	-0.05	0.07		-0.23	0.27	0.38	0.35	0.09	-0.22	-0.26	-0.42	-0.07	-0.07	0.29
-0.21	-0.36	-0.44	-0.40	0.02	-0.07	0.01			0.26	0.48	0.47	0.16	-0.23	-0.34	-0.40	-0.03	-0.03	0.29
-0.11	-0.31	-0.44	-0.31	0.04	-0.04	-0.02				0.49	0.49	0.22	-0.22	-0.33	-0.29	0.05	0.07	0.27
0.00	-0.18	-0.30	-0.18	0.03	-0.04	-0.05					0.40	0.24	-0.11	-0.20	-0.12	0.10	0.11	0.17
0.07	-0.08	-0.17	-0.08	0.01	-0.03	-0.05						0.24	-0.04	-0.07	-0.01	0.11	0.12	0.09
	-0.06	-0.12	-0.07	-0.03	-0.06	-0.07							0.00	-0.01	0.04	0.10	0.10	0.00
		-0.10	-0.07	-0.09	-0.10	-0.10								-0.01	0.03	0.07	0.06	-0.07
			-0.06	-0.11	-0.13	-0.13									0.06	0.08	0.06	-0.09
				-0.10	-0.15	-0.15										0.09	0.05	-0.11
					-0.16	-0.15											0.04	-0.11
						-0.17												-0.15
-0.22	-0.33	-0.33	-0.40	0.05	-0.03	0.12	-0.18	-0.21	0.24	0.32	0.29	0.08	-0.21	-0.22	-0.42	-0.06	-0.08	0.29
-0.23	-0.37	-0.38	-0.43	0.03	-0.07	0.08		-0.24	0.25	0.40	0.36	0.13	-0.21	-0.25	-0.41	-0.05	-0.08	0.28
-0.22	-0.39	-0.43	-0.41	0.03	-0.09	0.03			0.22	0.49	0.46	0.18	-0.24	-0.30	-0.37	0.00	-0.03	0.26
-0.15	-0.35	-0.43	-0.31	0.06	-0.08	-0.02				0.52	0.50	0.22	-0.23	-0.30	-0.26	0.08	0.04	0.23
-0.06	-0.24	-0.33	-0.18	0.07	-0.05	-0.03					0.44	0.23	-0.16	-0.20	-0.10	0.15	0.10	0.16
0.00	-0.14	-0.21	-0.10	0.03	-0.05	-0.05						0.22	-0.07	-0.08	0.00	0.14	0.10	0.07
	-0.08	-0.13	-0.07	-0.03	-0.08	-0.07							-0.01	-0.01	0.04	0.11	0.08	-0.02
		-0.10	-0.06	-0.08	-0.11	-0.09								0.01	0.05	0.09	0.06	-0.07
			-0.05	-0.10	-0.13	-0.12									0.07	0.09	0.06	-0.10
				-0.10	-0.15	-0.13										0.10	0.05	-0.12
					-0.18	-0.15											0.03	-0.14
						-0.18												-0.17
0.20	0.27	0.32	0.47	0.15	0.16	0.03	0.00	0.04	-0.34	-0.39	-0.38	-0.20	0.10	0.21	0.44	0.20	0.19	-0.09
0.15	0.24	0.28	0.44	0.14	0.12	0.02		0.10	-0.29	-0.41	-0.38	-0.23	0.10	0.18	0.43	0.16	0.13	-0.13
0.01	0.13	0.21	0.24	-0.01	0.02	0.00			-0.20	-0.44	-0.47	-0.27	0.10	0.19	0.27	-0.05	-0.06	-0.30
-0.01	0.15	0.18	0.21	-0.05	0.04	-0.04				-0.33	-0.32	-0.24	0.07	0.10	0.23	-0.05	-0.03	-0.32
-0.05	0.10	0.16	0.13	0.00	0.10	0.03					-0.27	-0.23	0.04	0.07	0.14	0.00	0.01	-0.23
0.06	0.20	0.24	0.18	0.06	0.16	0.04						-0.24	0.06	0.09	0.16	0.04	0.07	-0.13
	0.12	0.17	0.07	0.02	0.11	0.00							0.03	0.04	0.06	-0.05	0.01	-0.13
		0.14	0.04	0.00	0.12	-0.01								0.06	-0.01	-0.13	-0.01	-0.10
			0.04	-0.02	0.14	0.00									-0.05	-0.16	0.00	-0.06
				-0.02	0.15	-0.04										-0.19	-0.01	-0.06
					0.18	0.03											0.02	0.04
						0.07												0.08

ENSO		Area 1 % GOOD RAINFALL												Area 2 % GOOD RAINFALL				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
NINO3.4	JFM	-0.10	0.05	0.02	0.09	0.07	-0.04	-0.23	-0.31	0.01	0.03	-0.04	-0.21	-0.01	-0.21	-0.06	-0.15	-0.04
	FMA		-0.01	0.00	-0.07	-0.05	-0.11	-0.16	-0.24	-0.04	0.01	0.02	-0.11		-0.26	-0.08	-0.13	-0.02
	MAM			-0.08	-0.19	-0.21	-0.23	-0.12	0.04	0.17	0.21	0.20	0.14			-0.12	-0.12	0.03
	AMJ				-0.25	-0.33	-0.32	-0.18	0.00	0.17	0.29	0.26	0.15				-0.10	0.07
	MJJ					-0.11	-0.20	-0.14	-0.01	0.18	0.20	0.22	0.03					0.07
	JJA						-0.20	-0.11	-0.18	-0.02	-0.01	0.10	-0.07					
	JAS							-0.06	-0.20	-0.10	-0.09	0.05	0.05					
	ASO								-0.20	-0.03	0.01	0.07	0.13					
	SON									0.06	0.13	0.17	0.23					
	OND										0.07	0.08	0.12					
	NDJ											0.05	0.10					
	DJF												-0.05					
ONI	JFM	-0.17	-0.06	-0.11	0.07	0.07	0.14	0.21	0.29	0.39	0.20	0.05	-0.16	-0.01	-0.21	-0.04	-0.12	0.00
	FMA		-0.04	-0.08	0.05	0.06	0.08	0.18	0.28	0.42	0.23	0.07	-0.16		-0.25	-0.07	-0.12	0.01
	MAM			-0.09	0.04	-0.05	0.00	0.07	0.26	0.32	0.14	0.04	-0.12			-0.11	-0.11	0.04
	AMJ				0.13	-0.06	-0.08	-0.05	0.21	0.34	0.22	0.18	-0.05				-0.10	0.08
	MJJ					-0.15	-0.10	-0.08	0.21	0.25	0.25	0.26	0.08					0.10
	JJA						-0.11	0.03	0.23	0.19	0.20	0.25	0.16					
	JAS							0.06	0.22	0.13	0.16	0.23	0.17					
	ASO								0.15	0.07	0.08	0.14	0.09					
	SON									0.07	0.08	0.12	0.08					
	OND										-0.04	0.06	0.10					
	NDJ											0.00	0.11					
	DJF												0.19					
SOI	JFM	0.15	-0.13	-0.05	-0.19	-0.09	-0.12	-0.16	-0.25	-0.42	-0.20	-0.06	0.26	-0.04	0.10	0.02	0.09	0.01
	FMA		-0.12	-0.02	-0.15	-0.02	-0.08	-0.14	-0.25	-0.41	-0.19	-0.11	0.19		0.16	0.11	0.15	0.07
	MAM			0.03	-0.07	0.11	0.03	-0.11	-0.26	-0.37	-0.18	-0.16	0.06			0.18	0.17	-0.06
	AMJ				0.04	0.25	0.17	-0.07	-0.27	-0.29	-0.16	-0.21	-0.10				0.16	-0.10
	MJJ					0.33	0.26	-0.03	-0.25	-0.18	-0.12	-0.19	-0.18					-0.21
	JJA						0.28	0.00	-0.21	-0.11	-0.11	-0.14	-0.20					
	JAS							0.02	-0.19	-0.08	-0.11	-0.11	-0.20					
	ASO								-0.18	-0.06	-0.12	-0.09	-0.20					
	SON									-0.03	-0.12	-0.09	-0.21					
	OND										-0.10	-0.08	-0.21					
	NDJ											-0.07	-0.21					
	DJF												-0.22					

Area 2 % GOOD RAINFALL							Area 3 % GOOD RAINFALL											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.26	-0.27	-0.29	-0.41	0.03	0.00	0.21	-0.02	-0.09	0.11	0.10	0.23	0.12	-0.12	-0.22	-0.44	-0.21	-0.19	0.32
-0.27	-0.30	-0.33	-0.42	0.03	0.00	0.20		-0.12	0.09	0.15	0.29	0.15	-0.13	-0.24	-0.44	-0.20	-0.18	0.32
-0.25	-0.31	-0.37	-0.40	0.02	-0.01	0.16			0.08	0.26	0.39	0.19	-0.16	-0.29	-0.42	-0.17	-0.14	0.31
-0.21	-0.28	-0.35	-0.28	0.03	0.01	0.14				0.37	0.41	0.16	-0.19	-0.28	-0.31	-0.09	-0.06	0.27
-0.14	-0.21	-0.26	-0.15	0.02	0.00	0.07					0.35	0.12	-0.14	-0.17	-0.14	-0.03	-0.01	0.14
-0.08	-0.13	-0.16	-0.06	0.00	0.00	0.04						0.07	-0.10	-0.07	-0.02	0.01	0.01	0.02
	-0.11	-0.13	-0.04	-0.04	-0.01	0.00							-0.07	-0.02	0.04	0.04	0.02	-0.07
		-0.10	-0.02	-0.07	-0.04	-0.04								0.00	0.07	0.06	0.01	-0.14
			0.01	-0.09	-0.07	-0.07									0.11	0.09	0.04	-0.16
				-0.07	-0.09	-0.08										0.11	0.04	-0.16
					-0.10	-0.09											0.04	-0.17
						-0.12												-0.21
-0.23	-0.26	-0.28	-0.41	0.02	0.00	0.22	-0.04	-0.10	0.10	0.09	0.23	0.12	-0.13	-0.20	-0.42	-0.18	-0.17	0.33
-0.25	-0.29	-0.31	-0.41	0.02	-0.02	0.20		-0.14	0.07	0.16	0.30	0.16	-0.12	-0.21	-0.40	-0.16	-0.16	0.31
-0.25	-0.30	-0.33	-0.37	0.04	-0.02	0.17			0.04	0.26	0.38	0.20	-0.14	-0.22	-0.36	-0.11	-0.12	0.28
-0.22	-0.28	-0.31	-0.26	0.08	0.00	0.14				0.37	0.43	0.18	-0.17	-0.20	-0.25	-0.04	-0.06	0.23
-0.17	-0.21	-0.23	-0.12	0.09	0.03	0.11					0.38	0.11	-0.16	-0.13	-0.10	0.04	0.00	0.13
-0.13	-0.15	-0.16	-0.05	0.05	0.02	0.07						0.05	-0.12	-0.05	0.01	0.06	0.02	0.02
	-0.11	-0.12	-0.02	-0.01	-0.01	0.01							-0.09	0.00	0.07	0.07	0.02	-0.08
		-0.09	0.00	-0.06	-0.05	-0.04								0.02	0.10	0.08	0.02	-0.14
			0.02	-0.07	-0.07	-0.06									0.13	0.10	0.04	-0.16
				-0.06	-0.08	-0.07										0.13	0.05	-0.17
					-0.10	-0.09											0.04	-0.19
						-0.12												-0.22
0.19	0.20	0.31	0.43	0.02	0.02	-0.13	-0.12	-0.05	-0.22	-0.15	-0.35	-0.28	-0.01	0.21	0.39	0.20	0.19	-0.22
0.21	0.19	0.29	0.42	0.05	0.03	-0.13		-0.02	-0.20	-0.18	-0.29	-0.20	0.07	0.18	0.38	0.16	0.15	-0.23
0.10	0.06	0.16	0.26	0.07	0.08	-0.03			-0.17	-0.30	-0.36	-0.12	0.13	0.13	0.28	0.03	0.08	-0.33
0.05	0.06	0.11	0.20	0.15	0.16	0.01				-0.25	-0.27	-0.10	0.09	0.02	0.26	0.07	0.16	-0.27
-0.03	-0.02	0.07	0.07	0.14	0.19	0.09					-0.28	-0.15	-0.01	-0.02	0.15	0.07	0.19	-0.15
0.07	0.06	0.10	0.01	0.05	0.11	0.00						-0.13	0.03	-0.04	0.07	0.01	0.17	-0.07
	0.00	0.01	-0.10	-0.01	0.07	-0.03							0.10	-0.09	-0.06	-0.13	0.04	-0.09
		-0.04	-0.11	0.01	0.12	0.01								-0.10	-0.10	-0.15	0.04	-0.05
			-0.06	0.04	0.14	0.00									-0.11	-0.13	0.06	-0.03
				0.01	0.11	-0.02										-0.17	0.02	0.02
					0.12	0.04											0.01	0.12
						0.05												0.17

ENSO		Area 1 HEAVY RAINFALL												Area 2 HEAVY RAINFALL				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
NINO3.4	JFM	0.00	0.05	-0.08	-0.02	0.07	0.17	0.15	-0.26	-0.10	-0.10	0.09	0.00	-0.26	0.03	0.03	0.13	-0.02
	FMA		0.09	0.05	0.06	0.07	0.09	0.08	-0.13	-0.16	-0.16	-0.03	0.00		0.06	0.08	0.20	0.05
	MAM			-0.09	-0.14	-0.16	-0.18	-0.13	0.08	-0.07	-0.07	-0.12	0.00			0.14	0.29	0.12
	AMJ				-0.07	-0.15	-0.35	-0.36	0.04	-0.02	-0.02	-0.14	0.00				0.32	0.19
	MJJ					-0.08	-0.29	-0.25	0.06	0.07	0.07	-0.06	0.00					0.22
	JJA						-0.21	-0.16	0.07	-0.05	-0.05	-0.18	0.00					
	JAS							-0.11	0.11	-0.07	-0.07	-0.18	0.00					
	ASO								0.03	-0.08	-0.08	-0.12	0.00					
	SON									-0.01	-0.01	-0.05	0.00					
	OND										-0.20	-0.03	0.00					
	NDJ											-0.21	0.00					
	DJF												0.00					
ONI	JFM	0.00	-0.20	-0.03	-0.06	0.07	0.00	0.08	-0.04	0.08	0.08	0.08	0.00	-0.28	0.06	0.04	0.14	-0.03
	FMA		-0.20	-0.06	-0.08	0.05	0.00	0.07	-0.02	0.11	0.11	0.08	0.00		0.07	0.06	0.18	0.01
	MAM			-0.16	-0.20	-0.22	-0.17	-0.10	-0.03	0.05	0.05	0.00	0.00			0.08	0.23	0.06
	AMJ				-0.27	-0.31	-0.17	-0.11	-0.11	0.00	0.00	0.04	0.00				0.25	0.13
	MJJ					-0.39	-0.21	-0.16	-0.06	-0.01	-0.01	-0.01	0.00					0.18
	JJA						-0.12	-0.06	-0.09	-0.09	-0.09	-0.04	0.00					
	JAS							-0.12	-0.02	-0.04	-0.04	-0.05	0.00					
	ASO								-0.04	-0.11	-0.11	-0.16	0.00					
	SON									-0.16	-0.16	-0.23	0.00					
	OND										-0.23	-0.31	0.00					
	NDJ											-0.28	0.00					
	DJF												0.00					
SOI	JFM	0.00	0.11	-0.01	0.02	-0.09	-0.01	-0.07	0.09	-0.07	-0.07	-0.09	0.00	0.13	-0.19	-0.16	-0.25	-0.01
	FMA		0.12	0.04	0.05	-0.07	-0.05	-0.12	0.04	-0.07	-0.07	-0.06	0.00		-0.19	-0.14	-0.24	0.04
	MAM			0.10	0.09	-0.02	-0.08	-0.14	-0.04	-0.06	-0.06	0.00	0.00			-0.06	-0.18	-0.11
	AMJ				0.15	0.08	-0.04	-0.10	-0.09	-0.03	-0.03	0.08	0.00				-0.21	-0.21
	MJJ					0.18	0.03	-0.02	-0.05	0.04	0.04	0.15	0.00					-0.33
	JJA						0.08	0.04	0.04	0.10	0.10	0.17	0.00					
	JAS							0.08	0.09	0.15	0.15	0.19	0.00					
	ASO								0.09	0.15	0.15	0.22	0.00					
	SON									0.14	0.14	0.25	0.00					
	OND										0.14	0.28	0.00					
	NDJ											0.31	0.00					
	DJF												0.00					

Area 2 HEAVY RAINFALL							Area 3 HEAVY RAINFALL											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.05	-0.19	-0.15	-0.24	-0.04	0.00	0.29	0.00	0.10	0.15	0.11	0.03	0.01	-0.09	-0.06	-0.14	-0.01	0.00	0.00
-0.01	-0.17	-0.15	-0.22	-0.04	0.00	0.27		0.15	0.19	0.17	0.08	0.05	-0.09	-0.07	-0.14	-0.01	0.00	0.00
0.06	-0.14	-0.17	-0.23	-0.07	-0.01	0.23			0.24	0.23	0.14	0.11	-0.09	-0.09	-0.16	-0.02	0.00	0.00
0.15	-0.10	-0.20	-0.22	-0.14	-0.04	0.10				0.22	0.16	0.18	0.00	-0.06	-0.15	-0.03	0.00	0.00
0.20	-0.01	-0.18	-0.13	-0.15	-0.07	-0.07					0.13	0.23	0.11	0.03	-0.09	-0.01	0.00	0.00
0.20	0.05	-0.14	-0.07	-0.15	-0.12	-0.19						0.24	0.19	0.11	-0.03	0.03	0.00	0.00
	0.05	-0.07	0.00	-0.08	-0.11	-0.21							0.20	0.19	0.04	0.09	0.00	0.00
		-0.07	0.00	-0.06	-0.10	-0.20								0.21	0.04	0.09	0.00	0.00
			-0.01	-0.05	-0.06	-0.18									0.02	0.06	0.00	0.00
				-0.06	-0.02	-0.17										0.02	0.00	0.00
					-0.01	-0.18											0.00	0.00
						-0.22												0.00
-0.07	-0.21	-0.13	-0.22	-0.03	0.00	0.29	0.00	0.13	0.16	0.11	0.03	0.00	-0.10	-0.05	-0.12	0.02	0.00	0.00
-0.04	-0.21	-0.16	-0.22	-0.04	0.00	0.26		0.15	0.17	0.15	0.06	0.04	-0.09	-0.06	-0.13	0.00	0.00	0.00
0.01	-0.20	-0.21	-0.23	-0.06	0.01	0.23			0.16	0.17	0.08	0.10	-0.07	-0.06	-0.14	-0.02	0.00	0.00
0.09	-0.15	-0.23	-0.20	-0.08	0.01	0.13				0.16	0.10	0.17	0.01	-0.02	-0.12	-0.02	0.00	0.00
0.14	-0.08	-0.19	-0.12	-0.08	-0.02	0.00					0.10	0.23	0.11	0.08	-0.06	0.02	0.00	0.00
0.16	-0.01	-0.12	-0.04	-0.07	-0.07	-0.12						0.24	0.18	0.17	0.01	0.07	0.00	0.00
	0.01	-0.07	0.02	-0.05	-0.10	-0.19							0.20	0.22	0.06	0.11	0.00	0.00
		-0.06	0.02	-0.04	-0.09	-0.21								0.23	0.06	0.10	0.00	0.00
			0.01	-0.04	-0.06	-0.21									0.04	0.07	0.00	0.00
				-0.03	-0.03	-0.20										0.05	0.00	0.00
					-0.02	-0.22											0.00	0.00
						-0.25												0.00
0.01	0.17	0.08	0.19	-0.02	0.00	-0.22	0.00	-0.25	-0.28	-0.23	-0.09	-0.01	0.12	0.07	0.10	0.00	0.00	0.00
0.05	0.20	0.10	0.24	0.04	0.01	-0.24		-0.29	-0.28	-0.23	-0.07	-0.01	0.13	0.11	0.15	0.03	0.00	0.00
-0.09	0.04	0.08	0.21	0.06	0.02	-0.24			-0.16	-0.07	-0.08	-0.08	-0.06	0.06	0.18	0.02	0.00	0.00
-0.13	0.03	0.09	0.16	0.17	0.19	-0.04				-0.02	-0.07	-0.09	-0.09	0.01	0.10	-0.07	0.00	0.00
-0.22	-0.08	0.13	0.11	0.25	0.29	0.19					-0.11	-0.15	-0.20	-0.01	0.09	-0.03	0.00	0.00
-0.22	-0.02	0.09	0.02	0.14	0.25	0.27						-0.20	-0.20	-0.14	-0.06	-0.13	0.00	0.00
	0.01	0.12	0.06	0.14	0.20	0.23							-0.23	-0.11	-0.02	-0.07	0.00	0.00
		0.06	0.00	0.07	0.13	0.22								-0.14	-0.01	-0.06	0.00	0.00
			-0.02	0.03	0.09	0.19									-0.03	-0.09	0.00	0.00
				-0.05	0.04	0.23										-0.13	0.00	0.00
					0.03	0.25											0.00	0.00
						0.22												0.00

ENSO		Area 1 DRY DEKADS												Area 2 DRY DEKADS				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
NINO3.4	JFM	0.00	-0.10	-0.03	-0.20	-0.02	0.15	0.39	0.33	0.06	-0.09	0.00	-0.05	0.05	0.12	-0.01	-0.01	-0.08
	FMA		-0.33	-0.28	-0.20	0.11	0.24	0.42	0.31	0.24	0.01	0.10	-0.09		0.12	-0.03	-0.05	-0.13
	MAM			-0.21	-0.05	0.15	0.14	0.20	-0.02	-0.03	-0.16	-0.01	-0.19			0.01	-0.11	-0.19
	AMJ				0.09	0.04	0.03	0.02	-0.01	-0.02	-0.18	-0.20	-0.28				-0.21	-0.26
	MJJ					-0.06	0.09	0.01	0.09	-0.03	0.01	-0.12	-0.10					-0.23
	JJA						0.15	0.07	0.23	0.22	0.29	0.10	0.07					
	JAS							0.12	0.21	0.36	0.34	0.28	0.06					
	ASO								0.10	0.11	0.07	0.11	-0.06					
	SON									0.02	0.03	0.05	-0.14					
	OND										0.05	0.02	0.03					
	NDJ											0.04	0.10					
	DJF												0.03					
ONI	JFM	0.04	-0.06	-0.09	-0.04	0.02	-0.11	-0.14	-0.23	-0.32	-0.21	-0.22	-0.18	0.08	0.11	-0.02	-0.04	-0.08
	FMA		-0.11	-0.11	0.00	0.04	-0.04	-0.11	-0.20	-0.31	-0.24	-0.22	-0.20		0.11	-0.03	-0.08	-0.14
	MAM			-0.15	0.01	0.07	-0.02	-0.14	-0.19	-0.23	-0.10	-0.08	-0.09			-0.02	-0.16	-0.22
	AMJ				0.15	0.07	0.03	-0.21	-0.16	-0.29	-0.08	-0.12	-0.02				-0.24	-0.28
	MJJ					0.04	-0.03	-0.23	-0.16	-0.26	-0.10	-0.14	0.00					-0.25
	JJA						-0.02	-0.24	-0.18	-0.29	-0.15	-0.23	-0.06					
	JAS							-0.23	-0.16	-0.21	-0.10	-0.19	-0.07					
	ASO								-0.19	-0.18	-0.02	-0.12	0.00					
	SON									-0.14	0.05	-0.08	0.02					
	OND										0.08	-0.11	0.05					
	NDJ											-0.13	0.01					
	DJF												-0.02					
SOI	JFM	0.06	0.16	0.11	-0.02	-0.06	0.05	0.18	0.20	0.30	0.05	0.12	0.05	0.04	-0.01	0.05	-0.02	0.07
	FMA		0.15	0.06	-0.07	-0.12	0.01	0.17	0.21	0.30	0.07	0.17	0.10		-0.10	0.01	0.07	0.13
	MAM			0.00	-0.14	-0.21	-0.06	0.16	0.21	0.28	0.07	0.20	0.16			-0.17	0.06	0.10
	AMJ				-0.19	-0.25	-0.14	0.12	0.18	0.22	0.06	0.20	0.19				0.09	0.00
	MJJ					-0.20	-0.18	0.08	0.11	0.16	0.06	0.16	0.17					-0.05
	JJA						-0.19	0.03	0.04	0.13	0.09	0.13	0.14					
	JAS							0.02	0.01	0.12	0.13	0.13	0.12					
	ASO								0.02	0.12	0.15	0.13	0.11					
	SON									0.11	0.15	0.14	0.11					
	OND										0.13	0.15	0.11					
	NDJ											0.17	0.12					
	DJF												0.14					

Area 2 DRY DEKADS							Area 3 DRY DEKADS											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
0.11	0.17	0.00	0.08	-0.16	0.13	-0.01	0.06	0.16	-0.11	-0.18	-0.25	0.02	0.15	0.13	0.13	-0.07	0.12	0.04
0.09	0.18	0.05	0.12	-0.15	0.13	-0.01		0.15	-0.16	-0.27	-0.33	-0.01	0.17	0.16	0.16	-0.08	0.12	0.05
0.01	0.20	0.16	0.21	-0.11	0.12	0.02			-0.18	-0.40	-0.39	-0.08	0.22	0.22	0.22	-0.09	0.11	0.06
-0.15	0.17	0.20	0.26	-0.08	0.07	-0.01				-0.51	-0.39	-0.17	0.24	0.20	0.24	-0.14	0.04	0.02
-0.25	0.08	0.13	0.24	-0.01	0.05	0.00					-0.28	-0.20	0.19	0.10	0.22	-0.11	0.02	0.01
-0.28	0.00	0.04	0.18	0.04	0.03	0.01						-0.18	0.13	0.00	0.18	-0.06	0.00	-0.01
	0.00	0.01	0.17	0.09	0.06	0.05							0.12	-0.02	0.19	-0.01	0.01	0.00
		0.00	0.17	0.11	0.09	0.09								-0.01	0.20	0.02	0.02	0.00
			0.13	0.08	0.10	0.09									0.18	0.01	0.01	0.00
				0.03	0.10	0.08										-0.03	0.01	0.00
					0.10	0.06											0.03	-0.01
						0.06												0.01
0.11	0.19	0.02	0.09	-0.17	0.13	-0.01	0.05	0.14	-0.12	-0.20	-0.26	0.01	0.17	0.15	0.14	-0.09	0.10	0.02
0.07	0.19	0.05	0.13	-0.15	0.14	0.00		0.13	-0.16	-0.28	-0.32	-0.03	0.18	0.16	0.16	-0.08	0.12	0.05
-0.02	0.19	0.11	0.17	-0.14	0.14	0.03			-0.18	-0.39	-0.39	-0.09	0.20	0.18	0.19	-0.10	0.12	0.07
-0.15	0.15	0.14	0.20	-0.11	0.10	0.03				-0.48	-0.38	-0.15	0.22	0.16	0.19	-0.14	0.08	0.06
-0.24	0.09	0.10	0.19	-0.06	0.07	0.03					-0.28	-0.16	0.20	0.09	0.18	-0.14	0.03	0.03
-0.25	0.04	0.04	0.17	0.00	0.06	0.04						-0.14	0.16	0.02	0.18	-0.08	0.02	0.01
	0.02	0.00	0.15	0.05	0.08	0.06							0.14	-0.01	0.20	-0.03	0.02	-0.01
		-0.02	0.13	0.07	0.09	0.07								-0.02	0.20	0.00	0.02	-0.02
			0.10	0.05	0.09	0.08									0.18	-0.01	0.01	-0.02
				0.03	0.10	0.08										-0.02	0.02	-0.02
					0.12	0.08											0.05	-0.01
						0.09												0.02
-0.16	-0.14	-0.14	-0.17	-0.06	-0.22	-0.22	0.03	-0.03	0.12	0.13	0.25	-0.03	-0.08	-0.18	-0.17	-0.14	-0.24	-0.22
-0.07	-0.13	-0.13	-0.21	-0.08	-0.21	-0.19		-0.10	0.08	0.21	0.26	0.00	-0.12	-0.20	-0.21	-0.12	-0.19	-0.19
0.02	-0.14	-0.10	-0.25	-0.09	-0.18	-0.10			0.01	0.26	0.20	-0.03	-0.28	-0.22	-0.20	-0.01	-0.07	-0.07
0.03	-0.20	-0.03	-0.31	-0.11	-0.23	-0.03				0.36	0.07	-0.06	-0.41	-0.20	-0.33	0.01	-0.07	0.04
0.03	-0.16	-0.01	-0.29	-0.15	-0.23	-0.02					-0.01	-0.07	-0.39	-0.12	-0.29	0.00	-0.07	0.07
0.05	-0.21	-0.07	-0.31	-0.17	-0.26	-0.05						-0.03	-0.39	-0.14	-0.34	0.00	-0.09	0.10
	-0.16	-0.08	-0.25	-0.12	-0.17	-0.01							-0.35	-0.12	-0.26	0.08	0.00	0.12
		-0.07	-0.20	-0.05	-0.17	0.01								-0.14	-0.27	0.13	0.01	0.17
			-0.13	0.04	-0.13	0.03									-0.21	0.17	0.02	0.18
				0.01	-0.17	0.05										0.10	-0.07	0.16
					-0.14	0.08											-0.11	0.07
						0.02												0.07

Appendix C

Pearson's correlation coefficients obtained from comparing two AAO indices with wheat-specific rainfall characteristic indices over the 1980-2012 period from the three study areas.

C-1) *Wet days* index (number of days to receive >2mm);

C-2) *'Good' rainfall* index (number of days to receive >10mm);

C-3) *Percentage 'good' rainfall* index (ratio of *'good' rainfall'* events to *wet days*);

C-4) *Heavy rainfall* index (number of days to receive >25mm);

C-5) *Dry Dekads* index (number of dekads [10 days] to receive <10mm)

Highlighted coefficients are significant at the 10% significance level with darker shadings indicating greater significance (see key).

Appendix C Key			
ρ value	**Value**		**Significance**
	Negative	Positive	
0.1	-0.2913	0.2913	10.00%
0.05	-0.3440	0.3440	5.00%
0.025	-0.4032	0.4032	2.00%
0.01	-0.4421	0.4421	1.00%
0.005	-0.4770	0.4770	0.50%
0.0025	-0.5184	0.5184	0.20%
0.001	-0.5465	0.5465	0.10%

AAO		Area 1 WET DAYS												Area 2 WET DAYS				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
AAO	JFM	0.00	-0.08	-0.15	-0.04	0.04	0.07	0.01	-0.17	-0.13	-0.19	-0.15	0.04	-0.09	-0.21	-0.13	-0.01	0.09
	FMA		0.07	0.10	-0.07	-0.11	-0.14	-0.04	-0.14	-0.25	-0.19	-0.21	0.20		-0.05	0.20	0.12	0.04
	MAM			0.11	-0.13	-0.15	-0.13	-0.04	-0.05	-0.14	-0.07	-0.14	0.12			0.00	-0.17	-0.14
	AMJ				-0.17	-0.07	-0.09	0.05	-0.01	-0.13	0.03	0.02	0.15				-0.20	-0.06
	MJJ					-0.09	-0.15	0.03	-0.01	-0.14	-0.07	-0.07	-0.06					-0.15
	JJA						-0.19	-0.02	-0.03	-0.20	-0.14	-0.16	-0.05					
	JAS							-0.06	-0.08	-0.32	-0.23	-0.31	0.02					
	ASO								-0.10	-0.22	-0.09	-0.08	0.21					
	SON									-0.11	-0.13	-0.12	0.22					
	OND										-0.10	0.06	0.07					
	NDJ											0.03	0.07					
	DJF												0.04					
SAM	JFM	-0.06	-0.09	-0.02	0.14	-0.03	-0.20	-0.24	-0.04	0.01	0.14	-0.10	-0.15	-0.10	-0.18	-0.22	-0.06	-0.04
	FMA		-0.11	0.01	0.18	0.00	-0.21	-0.26	-0.09	-0.02	0.10	-0.12	-0.17		0.13	0.16	0.06	-0.12
	MAM			0.00	0.24	0.08	-0.17	-0.27	-0.16	-0.06	0.07	-0.11	-0.19			0.04	-0.22	-0.21
	AMJ				0.30	0.17	-0.02	-0.23	-0.20	-0.11	0.04	-0.08	-0.18				-0.10	0.01
	MJJ					0.18	0.12	-0.11	-0.14	-0.11	-0.01	-0.07	-0.13					-0.04
	JJA						0.21	-0.04	-0.08	-0.12	-0.05	-0.06	-0.08					
	JAS							-0.02	-0.07	-0.15	-0.11	-0.08	-0.07					
	ASO								-0.10	-0.19	-0.15	-0.11	-0.07					
	SON									-0.19	-0.14	-0.12	-0.08					
	OND										-0.12	-0.12	-0.09					
	NDJ											-0.14	-0.08					
	DJF												-0.09					

Area 2 WET DAYS							Area 3 WET DAYS											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
0.21	0.08	-0.09	-0.21	-0.20	-0.14	0.04	-0.21	-0.26	-0.33	-0.22	-0.10	-0.04	-0.02	-0.24	-0.21	-0.32	-0.24	-0.03
0.03	-0.03	-0.08	-0.33	-0.16	-0.21	0.17		-0.18	-0.06	-0.09	-0.17	-0.19	-0.17	-0.25	-0.38	-0.34	-0.30	0.13
-0.04	0.01	0.05	-0.18	-0.01	-0.10	0.13			-0.16	-0.30	-0.29	-0.25	-0.15	-0.11	-0.19	-0.17	-0.21	0.13
-0.03	0.10	0.09	-0.07	0.12	0.08	0.13				-0.34	-0.17	-0.15	0.01	-0.02	-0.08	-0.05	0.02	0.17
-0.16	0.07	0.05	-0.08	-0.02	-0.01	-0.05					-0.24	-0.24	-0.02	-0.06	-0.11	-0.16	-0.04	-0.02
-0.19	-0.01	-0.05	-0.21	-0.16	-0.15	-0.12						-0.19	-0.04	-0.06	-0.18	-0.23	-0.10	-0.09
	-0.02	-0.09	-0.40	-0.35	-0.38	-0.07							-0.08	-0.06	-0.36	-0.34	-0.31	-0.11
		-0.11	-0.29	-0.22	-0.24	-0.02								0.07	-0.15	-0.16	-0.12	-0.01
			-0.11	-0.15	-0.25	0.06									-0.04	-0.15	-0.15	0.05
				-0.14	-0.14	-0.09										-0.09	0.00	-0.07
					-0.17	-0.09											-0.01	-0.11
						-0.12												-0.05
0.05	-0.11	-0.25	-0.22	-0.13	-0.06	-0.02	-0.18	-0.25	-0.34	-0.21	-0.16	-0.10	-0.14	-0.35	-0.28	-0.31	-0.23	-0.09
-0.08	-0.18	-0.20	-0.33	-0.14	-0.17	0.07		-0.04	-0.02	-0.07	-0.31	-0.27	-0.31	-0.33	-0.44	-0.34	-0.32	0.01
-0.08	0.01	0.11	-0.11	0.08	-0.05	0.17			-0.09	-0.33	-0.37	-0.29	-0.19	-0.07	-0.16	-0.10	-0.18	0.14
-0.02	0.09	0.14	0.07	0.26	0.22	0.14				-0.27	-0.11	-0.18	-0.05	-0.01	0.08	0.16	0.20	0.14
-0.12	0.09	0.07	0.05	0.12	0.15	-0.06					-0.10	-0.23	-0.02	-0.07	0.07	0.04	0.15	-0.05
-0.09	-0.02	-0.09	-0.22	-0.13	-0.06	-0.23						-0.07	-0.02	-0.06	-0.12	-0.09	0.07	-0.19
	-0.07	-0.16	-0.53	-0.42	-0.43	-0.22							-0.04	-0.07	-0.45	-0.37	-0.28	-0.23
		-0.12	-0.30	-0.24	-0.28	-0.14								0.08	-0.13	-0.17	-0.16	-0.11
			-0.04	-0.17	-0.26	-0.06									0.05	-0.15	-0.17	-0.05
				-0.14	-0.16	-0.18										-0.08	-0.06	-0.16
					-0.18	-0.25											-0.05	-0.29
						-0.15												-0.05

AAO		Area 1 GOOD RAINFALL												Area 2 GOOD RAINFALL				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
AAO	JFM	-0.14	-0.04	-0.19	-0.02	-0.03	-0.02	-0.04	-0.06	0.28	0.13	0.11	-0.15	0.00	0.20	-0.09	0.03	-0.10
	FMA		0.05	0.05	-0.09	-0.20	-0.27	-0.15	-0.14	0.10	0.06	0.14	-0.02		0.21	0.12	0.06	-0.17
	MAM			0.06	-0.12	-0.24	-0.33	-0.19	-0.07	0.14	0.12	0.14	0.08			0.18	0.03	-0.22
	AMJ				-0.18	-0.24	-0.38	-0.12	-0.13	0.03	0.07	0.17	0.17				-0.02	-0.18
	MJJ					-0.16	-0.30	-0.08	-0.09	0.01	-0.03	0.10	0.04					-0.12
	JJA						-0.25	-0.10	-0.23	-0.10	-0.09	0.04	-0.05					
	JAS							-0.10	-0.26	-0.15	-0.10	-0.05	-0.06					
	ASO								-0.37	-0.14	-0.02	-0.02	0.04					
	SON									-0.10	0.00	0.01	0.23					
	OND										-0.06	0.00	0.20					
	NDJ											-0.07	0.19					
	DJF												0.12					
SAM	JFM	-0.08	-0.19	0.06	0.00	-0.06	-0.15	-0.26	-0.18	-0.34	-0.03	-0.03	0.19	-0.03	0.13	-0.19	-0.04	-0.14
	FMA		-0.18	0.11	0.04	-0.01	-0.14	-0.26	-0.20	-0.33	-0.02	-0.05	0.14		0.26	0.05	0.05	-0.17
	MAM			0.16	0.13	0.12	-0.05	-0.23	-0.27	-0.32	-0.02	-0.09	0.03			0.14	-0.06	-0.23
	AMJ				0.23	0.26	0.11	-0.16	-0.31	-0.29	-0.06	-0.16	-0.15				-0.09	-0.18
	MJJ					0.30	0.23	-0.05	-0.25	-0.18	-0.05	-0.16	-0.27					-0.06
	JJA						0.29	0.04	-0.17	-0.10	-0.08	-0.16	-0.32					
	JAS							0.04	-0.15	-0.07	-0.09	-0.13	-0.32					
	ASO								-0.16	-0.07	-0.12	-0.12	-0.33					
	SON									-0.05	-0.11	-0.12	-0.33					
	OND										-0.09	-0.12	-0.35					
	NDJ											-0.10	-0.34					
	DJF												-0.34					

Area 2 GOOD RAINFALL							**Area 3 GOOD RAINFALL**											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.05	-0.05	0.01	0.19	-0.03	-0.19	-0.06	-0.18	-0.13	-0.24	0.02	-0.03	-0.02	-0.04	0.05	0.28	0.06	-0.11	-0.29
-0.22	-0.19	-0.11	-0.21	-0.27	-0.40	-0.09		-0.03	0.10	0.20	0.12	0.04	0.00	0.03	-0.02	-0.17	-0.27	-0.19
-0.35	-0.25	-0.09	-0.12	-0.15	-0.26	0.01			0.09	0.13	-0.02	-0.05	-0.04	0.16	0.05	-0.10	-0.24	-0.20
-0.36	-0.17	-0.10	-0.07	-0.07	-0.06	0.09				-0.04	-0.08	-0.15	-0.02	0.04	-0.03	-0.03	-0.06	-0.08
-0.29	-0.09	-0.07	-0.06	-0.21	-0.14	-0.13					-0.04	-0.11	0.05	0.02	-0.04	-0.13	-0.14	-0.32
-0.22	-0.13	-0.25	-0.29	-0.38	-0.28	-0.29						0.14	0.11	-0.13	-0.23	-0.28	-0.18	-0.27
	-0.11	-0.25	-0.48	-0.48	-0.44	-0.27							0.22	-0.11	-0.31	-0.38	-0.30	-0.19
		-0.33	-0.37	-0.24	-0.16	-0.03								-0.22	-0.29	-0.24	-0.06	0.09
			-0.24	-0.20	-0.12	0.09									-0.22	-0.18	-0.10	0.05
				-0.10	0.03	0.09										-0.08	0.08	0.10
					0.01	0.07											0.05	0.14
						0.09												0.28
-0.11	-0.14	-0.16	0.09	-0.05	-0.17	-0.14	-0.19	-0.20	-0.28	0.01	0.02	-0.07	-0.20	-0.21	0.06	-0.06	-0.13	-0.18
-0.15	-0.20	-0.17	-0.22	-0.24	-0.37	-0.22		0.02	0.05	0.15	0.08	0.02	-0.05	-0.11	-0.18	-0.31	-0.28	-0.06
-0.29	-0.18	-0.01	-0.10	-0.11	-0.25	-0.04			0.09	0.03	-0.07	-0.07	0.06	0.22	0.06	-0.11	-0.22	-0.09
-0.35	-0.17	-0.10	-0.01	0.11	0.10	0.13				-0.18	-0.21	-0.35	-0.04	0.07	0.04	0.10	0.12	0.10
-0.33	-0.14	-0.16	-0.01	-0.08	0.01	-0.09					-0.05	-0.22	-0.05	-0.04	0.04	0.03	0.07	-0.22
-0.24	-0.18	-0.35	-0.32	-0.33	-0.16	-0.29						0.10	0.01	-0.23	-0.31	-0.25	-0.01	-0.15
	-0.17	-0.29	-0.59	-0.49	-0.39	-0.21							0.15	-0.14	-0.46	-0.41	-0.25	-0.11
		-0.25	-0.35	-0.23	-0.16	-0.01								-0.13	-0.26	-0.22	-0.11	0.01
			-0.32	-0.20	-0.10	0.09									-0.22	-0.19	-0.09	0.01
				-0.17	-0.03	-0.02										-0.14	0.02	0.00
					-0.01	-0.04											0.03	0.09
						0.03												0.25

AAO		**Area 1 % GOOD RAINFALL**												**Area 2 % GOOD RAINFALL**				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
AAO	JFM	-0.24	-0.04	-0.01	0.13	0.10	-0.03	-0.13	-0.07	0.22	0.18	0.01	-0.21	0.02	0.23	0.06	0.06	-0.04
	FMA		-0.09	0.04	-0.04	-0.08	-0.26	-0.18	-0.16	0.11	0.14	0.13	0.01		0.11	0.09	0.01	-0.12
	MAM			0.03	-0.08	-0.11	-0.27	-0.19	-0.03	0.20	0.23	0.20	0.14			0.22	0.09	-0.16
	AMJ				-0.11	-0.19	-0.29	-0.15	-0.01	0.24	0.29	0.30	0.19				0.06	-0.24
	MJJ					-0.09	-0.16	-0.02	0.08	0.24	0.21	0.26	0.08					-0.14
	JJA						-0.18	-0.02	-0.04	0.16	0.15	0.25	0.02					
	JAS							-0.01	-0.08	0.08	0.06	0.15	0.03					
	ASO								-0.24	0.08	0.11	0.16	0.09					
	SON									0.10	0.15	0.17	0.20					
	OND										0.09	0.06	0.12					
	NDJ											0.02	0.12					
	DJF												0.00					
SAM	JFM	0.17	-0.09	-0.02	-0.19	-0.11	-0.14	-0.20	-0.27	-0.42	-0.19	-0.05	0.25	0.06	0.15	0.00	0.02	0.00
	FMA		-0.09	0.00	-0.16	-0.05	-0.10	-0.18	-0.28	-0.41	-0.19	-0.08	0.20		0.08	0.08	0.06	0.01
	MAM			0.06	-0.06	0.08	0.00	-0.16	-0.33	-0.41	-0.19	-0.15	0.07			0.14	0.03	-0.17
	AMJ				0.06	0.23	0.16	-0.11	-0.33	-0.33	-0.19	-0.23	-0.12				-0.03	-0.33
	MJJ					0.29	0.25	-0.05	-0.27	-0.20	-0.15	-0.21	-0.22					-0.18
	JJA						0.28	0.02	-0.21	-0.11	-0.14	-0.18	-0.24					
	JAS							0.01	-0.20	-0.08	-0.13	-0.13	-0.23					
	ASO								-0.21	-0.07	-0.14	-0.11	-0.22					
	SON									-0.05	-0.13	-0.10	-0.21					
	OND										-0.12	-0.11	-0.22					
	NDJ											-0.09	-0.22					
	DJF												-0.23					

Area 2 % GOOD RAINFALL							**Area 3 % GOOD RAINFALL**											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.11	0.01	0.09	0.37	0.18	-0.12	-0.16	-0.18	-0.15	-0.20	0.08	0.02	-0.02	-0.01	0.21	0.31	0.18	-0.07	-0.33
-0.25	-0.13	-0.10	0.03	-0.08	-0.37	-0.31		-0.20	-0.13	0.14	0.19	0.15	0.13	0.17	0.07	0.02	-0.20	-0.31
-0.40	-0.27	-0.13	0.07	-0.10	-0.25	-0.21			0.00	0.19	0.12	0.13	0.04	0.16	0.07	0.02	-0.14	-0.33
-0.41	-0.31	-0.19	0.07	-0.01	0.00	-0.04				0.03	0.00	0.02	-0.05	0.01	0.02	0.09	0.08	-0.22
-0.24	-0.20	-0.17	0.07	-0.06	0.03	-0.11					0.04	0.10	0.04	-0.02	0.04	0.05	0.04	-0.37
-0.15	-0.20	-0.31	-0.12	-0.14	-0.03	-0.18						0.27	0.10	-0.14	-0.07	-0.02	-0.01	-0.30
	-0.16	-0.32	-0.28	-0.27	-0.23	-0.25							0.24	-0.11	-0.13	-0.11	-0.14	-0.24
		-0.41	-0.26	-0.11	-0.05	-0.04								-0.27	-0.18	-0.11	-0.04	-0.02
			-0.18	-0.08	-0.03	-0.01									-0.14	-0.09	-0.03	-0.08
				0.03	0.05	0.02										0.04	0.14	0.07
					0.00	-0.01											0.11	0.15
						0.09												0.34

-0.14	-0.04	-0.05	0.23	0.14	-0.11	-0.14	-0.10	-0.15	-0.18	0.04	0.10	-0.03	-0.14	-0.06	0.04	-0.01	-0.18	-0.15
-0.11	-0.06	-0.10	0.02	-0.07	-0.34	-0.31		-0.15	-0.08	0.12	0.23	0.17	0.13	0.01	-0.13	-0.16	-0.28	-0.08
-0.33	-0.25	-0.09	0.02	-0.18	-0.31	-0.29			-0.02	0.17	0.11	0.14	0.16	0.17	0.02	-0.04	-0.13	-0.22
-0.45	-0.40	-0.23	0.03	0.02	0.07	0.00				0.01	-0.12	-0.14	-0.04	-0.03	-0.02	0.08	0.20	-0.03
-0.35	-0.34	-0.28	0.04	-0.02	0.12	-0.04					0.02	-0.01	-0.08	-0.12	0.01	0.08	0.16	-0.27
-0.26	-0.31	-0.43	-0.22	-0.17	0.04	-0.10						0.17	-0.06	-0.32	-0.20	-0.06	0.11	-0.17
	-0.21	-0.35	-0.40	-0.35	-0.21	-0.17							0.13	-0.21	-0.24	-0.14	-0.07	-0.16
		-0.33	-0.30	-0.19	-0.10	-0.05								-0.23	-0.17	-0.10	-0.03	-0.08
			-0.31	-0.12	-0.01	0.02									-0.18	-0.14	-0.05	-0.09
				-0.04	0.00	-0.04										-0.09	0.05	0.02
					0.02	-0.01											0.06	0.17
						0.10												0.32

AAO		Area 1 HEAVY RAINFALL												Area 2 HEAVY RAINFALL				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
AAO	JFM	0.00	-0.13	-0.20	-0.22	-0.07	0.01	0.14	-0.25	-0.02	-0.02	0.13	0.00	0.01	-0.07	-0.24	-0.29	-0.37
	FMA		-0.12	-0.06	-0.14	-0.09	-0.13	0.01	-0.10	-0.02	-0.02	0.06	0.00		0.03	0.00	-0.17	-0.27
	MAM			-0.21	-0.24	-0.25	-0.21	-0.15	0.02	-0.03	-0.03	-0.06	0.00			-0.18	-0.27	-0.24
	AMJ				-0.16	-0.26	-0.35	-0.31	0.06	-0.01	-0.01	-0.14	0.00				-0.18	-0.13
	MJJ					-0.16	-0.32	-0.26	0.15	0.03	0.03	-0.19	0.00					-0.07
	JJA						-0.22	-0.12	0.19	0.05	0.05	-0.18	0.00					
	JAS							0.02	0.15	0.01	0.01	-0.15	0.00					
	ASO								-0.01	-0.07	-0.07	-0.09	0.00					
	SON									-0.06	-0.06	-0.16	0.00					
	OND										-0.21	-0.16	0.00					
	NDJ											-0.26	0.00					
	DJF												0.00					
SAM	JFM	0.00	0.09	-0.02	0.01	-0.11	-0.02	-0.10	0.06	-0.09	-0.09	-0.08	0.00	0.02	0.05	-0.14	-0.10	-0.29
	FMA		0.12	0.06	0.06	-0.07	-0.07	-0.15	0.04	-0.08	-0.08	-0.06	0.00		0.21	0.11	0.07	-0.07
	MAM			0.14	0.14	0.01	-0.07	-0.15	-0.04	-0.07	-0.07	-0.01	0.00			-0.09	-0.19	-0.17
	AMJ				0.22	0.14	-0.01	-0.11	-0.11	-0.04	-0.04	0.08	0.00				-0.19	-0.14
	MJJ					0.21	0.05	-0.02	-0.08	0.03	0.03	0.16	0.00					-0.10
	JJA						0.10	0.06	-0.02	0.07	0.07	0.18	0.00					
	JAS							0.06	0.05	0.13	0.13	0.20	0.00					
	ASO								0.06	0.13	0.13	0.20	0.00					
	SON									0.12	0.12	0.23	0.00					
	OND										0.10	0.26	0.00					
	NDJ											0.28	0.00					
	DJF												0.00					

Area 2 HEAVY RAINFALL							Area 3 HEAVY RAINFALL											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.25	-0.15	-0.09	0.07	0.20	0.18	-0.05	0.00	-0.07	-0.25	-0.20	-0.29	-0.17	-0.06	-0.04	0.03	-0.10	0.00	0.00
-0.33	-0.16	-0.11	0.05	0.22	0.07	-0.05		0.00	-0.06	-0.10	-0.15	-0.14	0.00	-0.05	-0.02	-0.09	0.00	0.00
-0.27	-0.15	-0.09	0.08	0.23	0.10	-0.03			-0.18	-0.22	-0.23	-0.36	-0.14	-0.04	0.15	0.04	0.00	0.00
-0.19	-0.05	0.02	0.14	0.30	0.21	0.11				-0.16	-0.21	-0.39	-0.15	0.06	0.27	0.12	0.00	0.00
-0.15	-0.11	0.12	0.21	0.31	0.17	0.06					-0.21	-0.39	-0.23	0.14	0.36	0.20	0.00	0.00
-0.04	-0.06	0.08	0.17	0.29	0.09	0.06						-0.19	-0.08	0.17	0.30	0.21	0.00	0.00
	-0.05	-0.03	0.07	0.14	-0.11	-0.12							-0.01	0.07	0.17	0.14	0.00	0.00
		-0.17	-0.05	-0.01	-0.10	-0.06								-0.17	-0.02	-0.02	0.00	0.00
			0.00	0.03	-0.13	-0.11									0.05	0.03	0.00	0.00
				-0.06	-0.03	0.05										-0.16	0.00	0.00
					-0.07	0.09											0.00	0.00
						0.20												0.00
-0.14	-0.19	-0.14	-0.09	0.05	0.11	0.00	0.00	0.08	-0.06	-0.04	-0.20	-0.14	-0.11	-0.12	-0.10	-0.16	0.00	0.00
-0.09	-0.12	-0.22	-0.09	0.02	-0.01	-0.08		0.18	0.15	0.09	0.01	-0.03	0.03	-0.12	-0.11	-0.17	0.00	0.00
-0.23	-0.13	-0.10	0.05	0.16	0.06	-0.02			-0.12	-0.16	-0.20	-0.31	-0.14	-0.03	0.12	0.02	0.00	0.00
-0.25	-0.08	0.04	0.17	0.29	0.33	0.27				-0.24	-0.34	-0.51	-0.20	0.09	0.24	0.08	0.00	0.00
-0.19	-0.13	0.11	0.21	0.33	0.32	0.21					-0.32	-0.47	-0.25	0.13	0.30	0.15	0.00	0.00
-0.05	-0.14	-0.04	0.00	0.18	0.16	0.24						-0.27	-0.15	0.07	0.18	0.13	0.00	0.00
	-0.10	-0.11	-0.09	0.07	-0.10	0.00							-0.06	0.03	0.11	0.13	0.00	0.00
		-0.09	-0.10	-0.02	-0.10	0.00								-0.17	-0.01	0.02	0.00	0.00
			0.02	0.07	-0.06	-0.05									0.01	0.01	0.00	0.00
				-0.07	0.03	0.07										-0.24	0.00	0.00
					0.02	0.19											0.00	0.00
						0.29												0.00

AAO		Area 1 DRY DEKADS												Area 2 DRY DEKADS				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
AAO	JFM	0.06	-0.07	-0.01	-0.22	-0.11	0.01	0.17	0.11	-0.17	-0.15	0.04	-0.05	0.17	0.19	0.34	0.02	0.00
	FMA		-0.15	-0.14	-0.16	0.03	0.19	0.28	0.20	0.08	-0.03	0.11	-0.13		0.19	0.20	0.12	0.17
	MAM			-0.18	-0.13	0.03	0.10	0.16	-0.02	-0.10	-0.13	0.01	-0.17			0.13	0.26	0.27
	AMJ				-0.02	-0.01	0.02	0.02	0.00	-0.03	-0.11	-0.10	-0.25				0.23	0.21
	MJJ					-0.04	0.07	-0.02	0.03	0.01	0.09	-0.01	-0.06					0.24
	JJA						0.19	0.06	0.18	0.17	0.25	0.11	0.02					
	JAS							0.16	0.22	0.25	0.24	0.21	-0.02					
	ASO								0.19	0.15	0.00	0.02	-0.18					
	SON									0.04	-0.03	0.00	-0.24					
	OND										0.01	-0.02	-0.06					
	NDJ											-0.02	-0.04					
	DJF												-0.03					
SAM	JFM	0.04	0.17	0.12	0.01	-0.05	0.08	0.18	0.20	0.29	0.06	0.13	0.07	0.10	0.22	0.48	0.14	0.15
	FMA		0.18	0.08	-0.03	-0.11	0.04	0.16	0.22	0.30	0.08	0.15	0.10		0.04	0.20	0.17	0.33
	MAM			0.00	-0.12	-0.19	-0.02	0.17	0.25	0.30	0.08	0.17	0.14			0.08	0.30	0.38
	AMJ				-0.19	-0.23	-0.12	0.14	0.21	0.26	0.07	0.16	0.15				0.12	0.15
	MJJ					-0.20	-0.19	0.05	0.09	0.16	0.06	0.13	0.13					0.14
	JJA						-0.22	0.00	0.00	0.10	0.09	0.11	0.11					
	JAS							0.00	0.00	0.10	0.13	0.11	0.11					
	ASO								0.04	0.13	0.18	0.14	0.12					
	SON									0.12	0.18	0.15	0.13					
	OND										0.14	0.16	0.13					
	NDJ											0.16	0.12					
	DJF												0.13					

Area 2 DRY DEKADS							**Area 3 DRY DEKADS**											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.07	0.20	0.19	0.12	0.11	0.14	0.09	0.17	0.13	0.38	0.22	0.26	0.15	0.21	0.13	0.12	0.14	0.24	0.14
0.15	0.36	0.15	0.31	0.11	0.28	0.10		0.05	0.11	0.10	0.24	0.18	0.25	0.16	0.41	0.29	0.35	0.10
0.26	0.34	0.00	0.10	-0.07	0.17	0.07			0.00	0.13	0.15	0.11	0.11	-0.02	0.23	0.19	0.32	0.17
0.21	0.26	0.03	0.08	-0.16	-0.02	-0.04				0.16	0.04	0.00	-0.02	-0.03	0.16	0.04	0.07	0.02
0.30	0.18	0.02	0.02	-0.02	0.07	0.20					0.13	0.14	-0.06	0.01	0.11	0.18	0.12	0.19
0.39	0.27	0.10	0.15	0.12	0.20	0.30						0.20	0.06	0.13	0.19	0.29	0.15	0.23
	0.31	0.14	0.30	0.27	0.41	0.36							0.17	0.20	0.34	0.40	0.31	0.25
		0.32	0.34	0.12	0.17	0.16								0.30	0.31	0.25	0.13	0.10
			0.25	0.14	0.21	0.12									0.18	0.24	0.16	0.07
				0.15	0.10	0.16										0.14	-0.02	0.06
					0.17	0.19											-0.06	-0.01
						0.11												-0.14
0.04	0.37	0.31	0.21	0.09	0.10	0.09	0.29	0.16	0.45	0.19	0.34	0.22	0.40	0.27	0.24	0.12	0.21	0.11
0.21	0.40	0.17	0.36	0.15	0.29	0.13		-0.11	0.03	0.03	0.37	0.23	0.39	0.19	0.46	0.22	0.28	0.02
0.29	0.33	-0.09	0.09	-0.10	0.15	0.00			-0.09	0.11	0.27	0.15	0.13	-0.11	0.23	0.11	0.25	0.09
0.14	0.24	0.02	0.13	-0.20	-0.12	-0.23				0.13	0.08	0.01	0.00	-0.10	0.08	-0.19	-0.12	-0.08
0.22	0.19	0.09	0.04	-0.10	-0.08	0.06					0.07	0.12	-0.03	0.03	0.04	-0.01	-0.04	0.16
0.28	0.27	0.17	0.25	0.11	0.10	0.23						0.11	0.07	0.15	0.20	0.13	-0.03	0.19
	0.30	0.20	0.44	0.35	0.42	0.41							0.10	0.20	0.41	0.37	0.22	0.20
		0.32	0.36	0.17	0.18	0.21								0.23	0.25	0.22	0.12	0.16
			0.26	0.18	0.19	0.16									0.15	0.28	0.18	0.15
				0.16	0.10	0.19										0.21	0.09	0.21
					0.17	0.27											0.00	0.15
						0.03												-0.09

Appendix D

Pearson's correlation coefficients obtained from comparing three South Atlantic SST indices with wheat-specific rainfall characteristic indices over the 1980-2012 period from the three study areas.

D-1) *Wet days* index (number of days to receive >2mm);

D-2) *'Good' rainfall* index (number of days to receive >10mm);

D-3) *Percentage 'good' rainfall* index (ratio of *'good' rainfall* events to *wet days*);

D-4) *Heavy rainfall* index (number of days to receive >25mm);

D-5) *Dry Dekads index* (number of dekads [10 days] to receive <10mm)

Highlighted coefficients are significant at the 10% significance level with darker shadings indicating greater significance (see key).

Appendix D Key			
ρ value	Value		Significance
	Negative	Positive	
0.1	-0.2913	0.2913	10.00%
0.05	-0.3440	0.3440	5.00%
0.025	-0.4032	0.4032	2.00%
0.01	-0.4421	0.4421	1.00%
0.005	-0.4770	0.4770	0.50%
0.0025	-0.5184	0.5184	0.20%
0.001	-0.5465	0.5465	0.10%

S. Atlantic SSTs		Area 1 WET DAYS												Area 2 WET DAYS				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
SADI	JFM	0.01	0.06	0.05	0.01	-0.07	-0.16	-0.09	0.15	0.14	0.18	-0.11	-0.06	0.17	0.10	0.11	0.02	-0.11
	FMA		0.12	-0.01	0.00	-0.06	-0.11	-0.05	0.19	0.20	0.24	-0.09	-0.05		0.16	-0.01	-0.09	-0.16
	MAM			-0.17	-0.05	-0.08	-0.06	-0.04	0.23	0.35	0.37	0.07	-0.06			-0.14	-0.08	-0.18
	AMJ				-0.24	-0.11	0.11	0.10	0.29	0.36	0.39	0.22	0.04				-0.04	-0.09
	MJJ					-0.11	0.18	0.26	0.34	0.34	0.28	0.31	0.12					0.03
	JJA						0.27	0.44	0.41	0.28	0.14	0.26	0.21					
	JAS							0.50	0.44	0.23	0.09	0.19	0.30					
	ASO								0.44	0.24	0.20	0.26	0.38					
	SON									0.12	0.17	0.23	0.37					
	OND										0.13	0.16	0.14					
	NDJ											-0.02	-0.06					
	DJF												-0.17					
SWAI	JFM	-0.14	-0.01	0.02	0.05	-0.04	-0.09	-0.01	0.07	0.21	0.15	0.09	-0.02	0.11	0.07	0.22	0.11	0.05
	FMA		0.06	0.00	0.08	0.02	0.03	0.04	0.07	0.21	0.20	0.08	0.03		0.10	0.12	0.01	0.03
	MAM			-0.09	0.11	0.00	0.08	-0.06	0.00	0.20	0.29	0.17	0.01			-0.05	0.00	-0.06
	AMJ				-0.03	-0.06	0.16	-0.05	0.01	0.13	0.31	0.28	0.06				0.02	-0.05
	MJJ					-0.19	0.10	-0.02	0.02	0.09	0.23	0.33	0.02					-0.08
	JJA						0.13	0.16	0.12	0.05	0.10	0.25	0.02					
	JAS							0.24	0.17	-0.04	-0.03	0.09	0.06					
	ASO								0.25	0.00	0.11	0.20	0.26					
	SON									0.06	0.14	0.24	0.32					
	OND										0.22	0.31	0.17					
	NDJ											0.14	-0.01					
	DJF												-0.10					
SCAI	JFM	-0.12	-0.08	-0.05	0.03	0.06	0.13	0.11	-0.13	0.00	-0.10	0.20	0.05	-0.12	-0.07	0.04	0.07	0.17
	FMA		-0.11	0.01	0.06	0.10	0.16	0.10	-0.18	-0.08	-0.14	0.18	0.08		-0.12	0.11	0.12	0.22
	MAM			0.13	0.16	0.11	0.14	0.00	-0.28	-0.27	-0.22	0.06	0.08			0.14	0.10	0.17
	AMJ				0.28	0.08	0.01	-0.17	-0.37	-0.33	-0.20	-0.02	0.01				0.06	0.06
	MJJ					-0.04	-0.15	-0.37	-0.42	-0.35	-0.14	-0.10	-0.14					-0.11
	JJA						-0.25	-0.45	-0.44	-0.34	-0.10	-0.12	-0.26					
	JAS							-0.47	-0.45	-0.36	-0.15	-0.18	-0.36					
	ASO								-0.40	-0.33	-0.19	-0.21	-0.34					
	SON									-0.13	-0.14	-0.15	-0.30					
	OND										-0.01	0.02	-0.11					
	NDJ											0.14	0.04					
	DJF												0.13					

Area 2 WET DAYS							**Area 3 WET DAYS**											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.26	-0.17	0.07	0.06	0.12	-0.05	0.06	0.20	0.14	0.26	0.22	-0.05	-0.27	-0.27	0.03	0.08	0.17	-0.04	0.06
-0.22	-0.12	0.15	0.16	0.17	-0.04	0.06		0.11	0.15	0.14	-0.05	-0.16	-0.17	0.16	0.14	0.22	0.00	0.07
-0.18	-0.13	0.18	0.28	0.28	0.11	0.03			-0.04	0.05	-0.05	-0.08	-0.11	0.23	0.28	0.36	0.19	0.07
-0.01	-0.02	0.24	0.33	0.30	0.23	0.05				-0.06	0.03	0.13	0.08	0.37	0.35	0.39	0.28	0.08
0.14	0.17	0.30	0.32	0.19	0.22	0.01					0.07	0.27	0.30	0.49	0.38	0.28	0.28	0.00
0.30	0.39	0.42	0.29	0.05	0.07	0.04						0.39	0.46	0.59	0.33	0.13	0.13	-0.03
	0.46	0.46	0.24	-0.06	-0.03	0.13							0.47	0.59	0.25	0.01	0.00	0.00
		0.41	0.21	-0.01	0.05	0.26								0.54	0.21	0.04	0.04	0.12
			0.02	-0.08	0.05	0.30									0.06	-0.03	0.02	0.15
				-0.15	-0.02	0.12										-0.07	-0.01	0.01
					-0.17	-0.01											-0.15	-0.04
						-0.02												0.02
-0.18	-0.08	0.01	0.26	0.16	0.23	0.02	0.08	0.02	0.21	0.23	0.08	-0.15	-0.09	0.03	0.23	0.16	0.22	0.18
-0.10	0.00	0.08	0.33	0.23	0.19	0.00		-0.03	0.08	0.13	0.11	0.00	0.01	0.12	0.26	0.20	0.20	0.15
-0.07	-0.10	0.00	0.31	0.32	0.27	-0.06			-0.10	0.06	0.05	0.06	-0.04	0.04	0.23	0.31	0.31	0.09
0.01	-0.10	0.02	0.27	0.36	0.34	-0.04				-0.03	0.05	0.15	-0.02	0.05	0.21	0.33	0.34	0.06
0.01	-0.08	0.02	0.21	0.25	0.28	-0.17					-0.01	0.15	0.04	0.06	0.17	0.22	0.31	-0.11
0.16	0.12	0.13	0.14	0.11	0.11	-0.20						0.22	0.19	0.16	0.13	0.08	0.15	-0.21
	0.24	0.19	0.02	-0.09	-0.09	-0.16							0.27	0.21	0.01	-0.08	-0.02	-0.25
		0.26	0.04	-0.02	0.04	0.07								0.28	0.02	0.00	0.10	0.00
			0.03	-0.06	0.08	0.17									0.06	-0.01	0.13	0.10
				-0.01	0.13	0.06										0.07	0.21	0.04
					-0.03	-0.08											0.05	-0.06
						-0.10												-0.03
0.18	0.15	-0.08	0.14	-0.01	0.24	-0.06	-0.18	-0.15	-0.15	-0.09	0.12	0.21	0.26	-0.01	0.08	-0.09	0.22	0.06
0.20	0.15	-0.12	0.07	-0.02	0.21	-0.07		-0.17	-0.13	-0.07	0.15	0.19	0.22	-0.10	0.03	-0.12	0.16	0.03
0.16	0.08	-0.22	-0.08	-0.07	0.10	-0.08			-0.04	-0.01	0.11	0.15	0.10	-0.25	-0.15	-0.18	0.03	-0.01
0.02	-0.08	-0.29	-0.16	-0.05	0.02	-0.10				0.05	0.01	-0.04	-0.13	-0.43	-0.26	-0.19	-0.04	-0.05
-0.17	-0.30	-0.38	-0.22	0.00	-0.01	-0.17					-0.11	-0.22	-0.36	-0.59	-0.33	-0.16	-0.07	-0.10
-0.26	-0.42	-0.45	-0.27	0.03	0.00	-0.23						-0.33	-0.46	-0.66	-0.33	-0.11	-0.04	-0.15
	-0.41	-0.45	-0.31	-0.01	-0.04	-0.33							-0.41	-0.62	-0.32	-0.08	-0.02	-0.22
		-0.35	-0.26	-0.01	-0.05	-0.32								-0.51	-0.28	-0.06	0.01	-0.19
			0.00	0.06	-0.02	-0.32									-0.04	0.04	0.08	-0.15
				0.19	0.12	-0.17										0.16	0.19	-0.01
					0.18	-0.09											0.25	0.00
						-0.07												-0.05

S. Atlantic		Area 1 GOOD RAINFALL												Area 2 GOOD RAINFALL				
SSTs		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
SADI	JFM	0.17	-0.06	0.02	-0.08	-0.11	-0.12	-0.14	0.05	-0.03	0.21	0.09	0.13	0.00	-0.25	0.03	0.07	0.05
	FMA		-0.09	-0.12	-0.13	-0.07	-0.01	-0.01	0.10	-0.03	0.13	-0.02	0.04		-0.19	-0.05	0.07	0.12
	MAM			-0.28	-0.16	-0.04	0.09	0.10	0.16	0.02	0.06	-0.06	-0.06			-0.23	-0.01	0.08
	AMJ				-0.24	-0.03	0.15	0.21	0.14	0.01	-0.02	0.00	-0.07				-0.22	0.01
	MJJ					-0.06	0.12	0.26	0.06	0.01	-0.05	0.08	-0.07					-0.06
	JJA						0.07	0.31	0.03	0.02	-0.03	0.09	-0.01					
	JAS							0.28	0.06	0.05	0.03	0.12	0.10					
	ASO								0.17	0.16	0.13	0.19	0.17					
	SON									0.24	0.18	0.22	0.19					
	OND										0.17	0.11	-0.05					
	NDJ											-0.05	-0.27					
	DJF												-0.33					
SWAI	JFM	0.11	-0.01	-0.09	-0.01	-0.05	-0.02	-0.10	-0.01	0.01	0.11	0.01	-0.22	0.10	-0.09	-0.05	0.08	0.05
	FMA		0.02	-0.16	-0.02	0.03	0.10	0.00	-0.09	-0.01	0.08	-0.03	-0.28		-0.03	-0.09	0.11	0.16
	MAM			-0.22	0.02	0.08	0.20	0.01	-0.11	-0.03	0.02	-0.02	-0.32			-0.21	0.08	0.11
	AMJ				-0.02	0.07	0.20	0.04	-0.15	-0.09	-0.04	0.02	-0.24				-0.11	0.02
	MJJ					-0.03	0.10	0.01	-0.20	-0.17	-0.15	0.04	-0.21					-0.14
	JJA						0.01	0.06	-0.18	-0.21	-0.16	0.07	-0.12					
	JAS							0.02	-0.18	-0.25	-0.17	0.04	-0.05					
	ASO								-0.02	-0.11	0.00	0.18	0.11					
	SON									0.05	0.12	0.24	0.18					
	OND										0.20	0.23	0.07					
	NDJ											0.01	-0.12					
	DJF												-0.20					
SCAI	JFM	-0.12	0.06	-0.09	0.09	0.09	0.13	0.08	-0.07	0.05	-0.17	-0.10	-0.32	0.08	0.24	-0.07	-0.01	-0.03
	FMA		0.12	0.02	0.14	0.12	0.10	0.01	-0.19	0.03	-0.09	0.01	-0.28		0.22	-0.01	0.00	-0.02
	MAM			0.17	0.22	0.12	0.05	-0.11	-0.30	-0.05	-0.06	0.05	-0.20			0.11	0.08	-0.01
	AMJ				0.29	0.11	-0.01	-0.23	-0.32	-0.10	-0.02	0.01	-0.14				0.19	0.01
	MJJ					0.05	-0.06	-0.33	-0.25	-0.17	-0.07	-0.07	-0.11					-0.05
	JJA						-0.09	-0.36	-0.21	-0.22	-0.10	-0.07	-0.10					
	JAS							-0.37	-0.24	-0.30	-0.19	-0.14	-0.18					
	ASO								-0.26	-0.34	-0.20	-0.14	-0.16					
	SON									-0.33	-0.17	-0.13	-0.13					
	OND										-0.08	0.02	0.09					
	NDJ											0.07	0.21					
	DJF												0.26					

Area 2 GOOD RAINFALL							Area 3 GOOD RAINFALL											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
-0.13	-0.28	-0.17	-0.27	0.13	0.00	0.11	0.07	0.00	0.22	0.18	0.19	0.07	0.01	0.06	-0.06	0.04	-0.07	0.24
0.06	-0.11	-0.01	-0.09	0.16	0.01	0.04		0.10	0.11	0.13	0.14	0.19	0.11	0.12	-0.05	0.06	-0.05	0.33
0.13	-0.01	0.09	0.14	0.22	0.10	-0.04			-0.11	0.08	0.07	0.20	0.06	0.12	0.02	0.12	0.08	0.38
0.21	0.17	0.19	0.22	0.17	0.15	-0.06				-0.02	0.05	0.22	0.11	0.13	0.04	0.13	0.18	0.36
0.22	0.28	0.20	0.17	0.07	0.18	-0.07					0.08	0.22	0.20	0.11	0.03	0.08	0.28	0.32
0.30	0.41	0.27	0.05	0.00	0.14	0.01						0.22	0.38	0.18	0.02	0.04	0.24	0.29
	0.47	0.32	-0.02	-0.04	0.08	0.08							0.45	0.25	0.03	0.00	0.15	0.27
		0.38	0.04	0.00	0.08	0.13								0.30	0.10	0.06	0.14	0.26
			0.10	-0.01	0.02	0.12									0.15	0.10	0.08	0.16
				0.00	-0.05	-0.02										0.18	0.05	-0.03
					-0.20	-0.12											-0.11	-0.24
						-0.15												-0.28
-0.10	-0.25	-0.25	-0.03	0.13	0.13	-0.10	0.06	-0.04	-0.08	-0.06	-0.03	-0.13	-0.08	-0.11	0.08	0.03	0.15	0.14
0.10	-0.10	-0.16	0.09	0.13	0.10	-0.16		0.07	-0.09	-0.02	0.02	0.02	0.02	-0.09	0.09	0.08	0.17	0.20
0.15	-0.06	-0.12	0.19	0.13	0.10	-0.22			-0.23	0.00	-0.03	0.01	-0.13	-0.15	0.07	0.11	0.23	0.18
0.15	0.03	-0.04	0.19	0.09	0.13	-0.17				-0.01	-0.02	0.02	-0.17	-0.15	0.03	0.12	0.27	0.15
0.08	0.06	-0.01	0.11	0.01	0.16	-0.17					0.00	0.01	-0.18	-0.19	-0.06	0.04	0.31	0.08
0.08	0.16	0.07	-0.02	-0.04	0.13	-0.08						0.05	0.03	-0.06	-0.09	0.01	0.28	0.10
	0.21	0.10	-0.17	-0.15	0.03	-0.03							0.17	0.03	-0.16	-0.08	0.18	0.11
		0.19	-0.12	-0.08	0.09	0.09								0.15	-0.10	0.02	0.23	0.24
			-0.03	-0.07	0.09	0.13									-0.03	0.04	0.22	0.20
				0.05	0.17	0.07										0.16	0.29	0.11
					0.02	-0.04											0.10	-0.08
						-0.11												-0.15
0.08	0.14	0.01	0.31	-0.05	0.10	-0.21	-0.05	-0.03	-0.33	-0.27	-0.26	-0.19	-0.08	-0.16	0.14	-0.03	0.20	-0.18
0.01	0.06	-0.11	0.19	-0.09	0.06	-0.19		-0.07	-0.21	-0.18	-0.16	-0.22	-0.12	-0.21	0.13	-0.01	0.20	-0.25
-0.04	-0.04	-0.21	-0.01	-0.16	-0.03	-0.14			-0.05	-0.10	-0.11	-0.24	-0.18	-0.28	0.03	-0.06	0.10	-0.32
-0.12	-0.20	-0.28	-0.10	-0.13	-0.07	-0.09				0.01	-0.08	-0.27	-0.31	-0.31	-0.02	-0.05	0.02	-0.32
-0.22	-0.32	-0.27	-0.11	-0.09	-0.09	-0.08					-0.10	-0.27	-0.43	-0.31	-0.09	-0.07	-0.07	-0.34
-0.33	-0.41	-0.30	-0.08	-0.04	-0.07	-0.09						-0.26	-0.49	-0.30	-0.12	-0.04	-0.07	-0.31
	-0.46	-0.35	-0.13	-0.08	-0.09	-0.14							-0.47	-0.32	-0.20	-0.07	-0.05	-0.27
		-0.37	-0.17	-0.08	-0.05	-0.11								-0.30	-0.24	-0.08	-0.01	-0.18
			-0.20	-0.05	0.05	-0.08									-0.26	-0.12	0.08	-0.06
				0.04	0.22	0.07										-0.12	0.19	0.12
					0.27	0.10											0.23	0.22
						0.10												0.24

S. Atlantic		Area 1 % GOOD RAINFALL												Area 2 % GOOD RAINFALL				
SSTs		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
SADI	JFM	0.29	0.01	-0.01	-0.19	-0.12	-0.06	-0.05	0.00	-0.17	-0.03	-0.01	0.09	0.00	-0.21	-0.10	-0.07	0.10
	FMA		-0.03	-0.14	-0.20	-0.14	0.00	0.01	0.03	-0.19	-0.10	-0.07	0.02		-0.17	-0.10	0.00	0.15
	MAM			-0.23	-0.22	-0.16	0.02	0.07	0.06	-0.17	-0.13	-0.07	-0.04			-0.19	-0.05	0.10
	AMJ				-0.25	-0.20	-0.02	0.09	-0.01	-0.13	-0.13	0.03	-0.01				-0.20	-0.03
	MJJ					-0.25	-0.14	0.04	-0.10	0.01	-0.02	0.21	0.06					-0.17
	JJA						-0.20	0.00	-0.14	0.10	0.07	0.29	0.12					
	JAS							-0.02	-0.06	0.17	0.13	0.30	0.18					
	ASO								0.12	0.24	0.19	0.31	0.22					
	SON									0.28	0.20	0.25	0.19					
	OND										0.16	0.10	-0.04					
	NDJ											-0.09	-0.24					
	DJF												-0.26					
SWAI	JFM	0.21	0.13	-0.03	0.00	-0.07	0.06	-0.12	0.01	-0.02	0.04	-0.10	-0.32	0.08	-0.14	-0.26	-0.04	-0.01
	FMA		0.11	-0.09	0.03	-0.07	0.11	-0.13	-0.11	-0.05	0.01	-0.11	-0.36		-0.09	-0.23	0.05	0.05
	MAM			-0.09	0.09	0.00	0.18	-0.09	-0.15	-0.08	-0.05	-0.11	-0.35			-0.23	0.06	0.03
	AMJ				0.05	-0.01	0.15	-0.03	-0.21	-0.11	-0.10	-0.06	-0.24				-0.09	-0.05
	MJJ					-0.06	0.04	-0.06	-0.27	-0.10	-0.09	0.05	-0.13					-0.19
	JJA						-0.07	-0.11	-0.32	-0.07	-0.03	0.17	0.00					
	JAS							-0.20	-0.30	-0.05	0.01	0.18	0.06					
	ASO								-0.07	0.09	0.16	0.32	0.19					
	SON									0.28	0.30	0.37	0.21					
	OND										0.37	0.32	0.06					
	NDJ											0.08	-0.16					
	DJF												-0.21					
SCAI	JFM	-0.19	0.09	-0.01	0.23	0.09	0.13	-0.03	0.01	0.19	0.07	-0.06	-0.36	0.06	0.15	-0.08	0.06	-0.12
	FMA		0.13	0.10	0.28	0.13	0.10	-0.13	-0.12	0.20	0.13	0.01	-0.31		0.14	-0.06	0.05	-0.15
	MAM			0.21	0.34	0.19	0.13	-0.17	-0.20	0.13	0.12	0.00	-0.25			0.04	0.11	-0.10
	AMJ				0.37	0.25	0.18	-0.15	-0.18	0.05	0.07	-0.10	-0.21				0.17	-0.01
	MJJ					0.27	0.23	-0.09	-0.11	-0.10	-0.07	-0.24	-0.19					0.05
	JJA						0.21	-0.11	-0.11	-0.21	-0.13	-0.24	-0.16					
	JAS							-0.15	-0.18	-0.28	-0.18	-0.25	-0.20					
	ASO								-0.25	-0.28	-0.14	-0.18	-0.16					
	SON									-0.18	-0.04	-0.06	-0.11					
	OND										0.09	0.12	0.06					
	NDJ											0.19	0.14					
	DJF												0.16					

Area 2 % GOOD RAINFALL							**Area 3 % GOOD RAINFALL**											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
0.04	-0.25	-0.23	-0.42	-0.08	-0.03	0.09	0.08	0.02	0.10	0.01	0.28	0.29	0.25	0.03	-0.21	-0.19	-0.23	0.18
0.21	-0.07	-0.03	-0.26	-0.10	-0.02	0.07		0.17	0.12	0.00	0.18	0.32	0.26	0.07	-0.22	-0.18	-0.22	0.32
0.22	0.08	0.13	-0.07	-0.09	0.01	0.03			0.03	-0.02	0.05	0.20	0.13	0.08	-0.14	-0.08	-0.07	0.41
0.14	0.18	0.18	0.02	-0.10	0.02	-0.02				-0.05	-0.03	0.09	0.07	0.02	-0.05	0.06	0.15	0.41
0.03	0.15	0.10	0.00	-0.09	0.08	-0.05					-0.01	0.04	0.07	-0.05	-0.01	0.10	0.31	0.33
0.03	0.10	0.04	-0.08	-0.08	0.07	-0.06						0.10	0.23	-0.03	-0.02	0.05	0.30	0.24
	0.17	0.08	-0.10	-0.08	-0.01	-0.07							0.35	0.06	-0.01	0.00	0.18	0.21
		0.20	-0.03	-0.04	-0.04	-0.08								0.16	0.08	0.09	0.20	0.24
			0.09	0.01	-0.11	-0.12									0.17	0.19	0.16	0.16
				0.11	-0.06	-0.13										0.27	0.16	0.00
					-0.06	-0.08											-0.03	-0.24
						-0.01												-0.30
0.05	-0.24	-0.22	-0.18	0.04	0.16	0.09	0.08	0.02	-0.07	-0.14	-0.03	-0.02	0.04	-0.12	-0.07	-0.15	0.00	0.14
0.16	-0.18	-0.16	-0.08	-0.01	0.16	0.06		0.21	0.04	-0.01	-0.02	0.05	0.02	-0.15	-0.12	-0.16	-0.02	0.22
0.14	-0.11	-0.07	0.02	-0.08	0.11	0.02			0.00	0.05	-0.08	-0.06	-0.19	-0.20	-0.12	-0.12	0.02	0.22
0.08	-0.01	-0.03	0.04	-0.16	0.06	-0.03				0.04	-0.07	-0.09	-0.24	-0.22	-0.07	-0.02	0.15	0.18
-0.01	0.00	-0.05	0.00	-0.18	0.10	-0.04					-0.04	-0.08	-0.25	-0.25	-0.08	-0.01	0.22	0.08
-0.10	-0.04	-0.10	-0.09	-0.10	0.12	-0.01						0.00	-0.05	-0.17	-0.11	-0.01	0.25	0.06
	-0.03	-0.10	-0.15	-0.11	0.07	0.02							0.08	-0.09	-0.13	-0.06	0.17	0.09
		0.02	-0.10	-0.07	0.08	0.05								0.04	-0.03	0.08	0.28	0.23
			0.01	0.00	0.08	0.04									0.08	0.16	0.30	0.19
				0.16	0.19	0.04										0.24	0.37	0.10
					0.16	0.05											0.15	-0.13
						0.08												-0.17
-0.01	0.12	0.10	0.38	0.13	0.17	-0.05	-0.03	0.00	-0.18	-0.12	-0.37	-0.38	-0.27	-0.14	0.20	0.12	0.27	-0.11
-0.14	-0.05	-0.09	0.27	0.12	0.15	-0.04		-0.04	-0.13	-0.01	-0.25	-0.36	-0.32	-0.21	0.17	0.10	0.26	-0.23
-0.15	-0.19	-0.23	0.10	0.04	0.08	-0.02			-0.03	0.07	-0.13	-0.30	-0.33	-0.26	0.07	-0.01	0.11	-0.32
-0.11	-0.24	-0.27	0.01	-0.02	0.02	0.00				0.11	-0.02	-0.19	-0.31	-0.23	-0.01	-0.10	-0.06	-0.36
-0.05	-0.18	-0.17	-0.01	-0.05	-0.01	0.04					-0.02	-0.13	-0.32	-0.16	-0.06	-0.14	-0.20	-0.35
-0.14	-0.17	-0.14	0.03	0.01	0.02	0.07						-0.14	-0.36	-0.12	-0.07	-0.07	-0.18	-0.28
	-0.26	-0.20	0.00	0.02	0.08	0.11							-0.40	-0.17	-0.11	-0.05	-0.10	-0.21
		-0.27	-0.06	-0.01	0.13	0.15								-0.21	-0.15	-0.07	-0.06	-0.15
			-0.13	-0.02	0.24	0.21									-0.19	-0.16	0.01	-0.08
				-0.01	0.28	0.23										-0.19	0.09	0.07
					0.24	0.15											0.17	0.19
						0.07												0.23

S. Atlantic SSTs		Area 1 HEAVY RAINFALL												Area 2 HEAVY RAINFALL				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
SADI	JFM	0.00	-0.01	0.16	0.12	0.04	-0.12	-0.16	0.36	0.38	0.38	0.12	0.00	-0.27	0.01	0.20	0.26	0.32
	FMA		0.04	0.13	0.13	0.09	0.00	-0.03	0.37	0.34	0.34	0.05	0.00		-0.02	0.11	0.21	0.35
	MAM			0.03	0.06	0.10	0.11	0.10	0.29	0.19	0.19	0.01	0.00			-0.12	0.01	0.21
	AMJ				0.01	0.08	0.18	0.16	0.18	0.01	0.01	-0.04	0.00				-0.20	0.02
	MJJ					-0.01	0.14	0.18	0.05	-0.14	-0.14	-0.07	0.00					0.00
	JJA						0.06	0.13	-0.03	-0.18	-0.18	-0.09	0.00					
	JAS							0.26	-0.01	-0.14	-0.14	-0.06	0.00					
	ASO								0.02	-0.11	-0.11	-0.07	0.00					
	SON									-0.08	-0.08	-0.10	0.00					
	OND										-0.04	-0.09	0.00					
	NDJ											0.03	0.00					
	DJF												0.00					
SWAI	JFM	0.00	0.09	0.15	0.11	0.03	-0.15	-0.19	0.10	0.35	0.35	0.29	0.00	-0.26	0.04	0.16	0.27	0.27
	FMA		0.13	0.06	0.06	0.06	0.03	0.01	0.12	0.37	0.37	0.29	0.00		0.05	0.06	0.18	0.27
	MAM			-0.05	0.00	0.07	0.16	0.14	0.05	0.25	0.25	0.27	0.00			-0.16	0.00	0.04
	AMJ				-0.03	0.07	0.18	0.15	-0.01	0.12	0.12	0.20	0.00				-0.15	-0.11
	MJJ					-0.06	0.09	0.15	-0.05	-0.01	-0.01	0.14	0.00					-0.15
	JJA						-0.03	0.07	-0.06	-0.08	-0.08	0.06	0.00					
	JAS							0.15	-0.06	-0.09	-0.09	0.05	0.00					
	ASO								0.05	-0.02	-0.02	0.02	0.00					
	SON									-0.03	-0.03	-0.02	0.00					
	OND										-0.07	-0.03	0.00					
	NDJ											0.01	0.00					
	DJF												0.00					
SCAI	JFM	0.00	0.09	-0.08	-0.06	-0.03	0.03	0.05	-0.36	-0.19	-0.19	0.07	0.00	0.12	0.01	-0.12	-0.11	-0.17
	FMA		0.06	-0.12	-0.11	-0.06	0.02	0.05	-0.37	-0.13	-0.13	0.16	0.00		0.06	-0.09	-0.12	-0.23
	MAM			-0.08	-0.07	-0.06	0.00	0.00	-0.32	-0.02	-0.02	0.22	0.00			0.02	-0.02	-0.22
	AMJ				-0.03	-0.03	-0.05	-0.06	-0.23	0.10	0.10	0.24	0.00				0.12	-0.13
	MJJ					-0.04	-0.09	-0.10	-0.10	0.17	0.17	0.22	0.00					-0.14
	JJA						-0.11	-0.11	-0.02	0.17	0.17	0.18	0.00					
	JAS							-0.22	-0.04	0.10	0.10	0.13	0.00					
	ASO								0.00	0.13	0.13	0.12	0.00					
	SON									0.09	0.09	0.14	0.00					
	OND										-0.01	0.13	0.00					
	NDJ											-0.01	0.00					
	DJF												0.00					

Area 2 HEAVY RAINFALL							Area 3 HEAVY RAINFALL											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
0.14	0.12	0.29	0.33	0.12	-0.14	-0.14	0.00	0.04	0.18	0.18	0.18	0.11	-0.03	0.25	0.20	0.30	0.00	0.00
0.27	0.22	0.27	0.25	0.06	-0.17	-0.13		0.01	0.14	0.13	0.18	0.13	0.03	0.30	0.24	0.35	0.00	0.00
0.22	0.16	0.15	0.08	-0.02	-0.06	0.05			-0.03	-0.08	0.02	0.04	0.09	0.27	0.15	0.24	0.00	0.00
0.11	0.16	0.04	-0.09	-0.07	0.02	0.19				-0.23	-0.13	-0.03	0.15	0.19	0.01	0.08	0.00	0.00
0.10	0.24	-0.11	-0.21	-0.04	0.15	0.35					-0.15	-0.02	0.28	0.10	-0.11	-0.07	0.00	0.00
0.15	0.38	-0.17	-0.23	-0.02	0.12	0.29						0.06	0.36	0.04	-0.14	-0.12	0.00	0.00
	0.45	-0.11	-0.15	-0.04	0.00	0.11							0.45	0.00	-0.15	-0.13	0.00	0.00
		-0.05	-0.08	-0.06	-0.07	0.01								-0.01	-0.16	-0.13	0.00	0.00
			-0.01	-0.08	-0.19	-0.14									-0.13	-0.11	0.00	0.00
				-0.06	-0.20	-0.20										0.00	0.00	0.00
					-0.27	-0.36											0.00	0.00
						-0.33												0.00
0.17	0.14	0.25	0.34	0.10	0.06	-0.09	0.00	0.13	0.20	0.28	0.22	0.20	-0.02	0.20	0.14	0.17	0.00	0.00
0.29	0.23	0.21	0.28	0.14	0.10	-0.04		0.11	0.16	0.18	0.17	0.16	0.05	0.26	0.24	0.27	0.00	0.00
0.19	0.07	0.07	0.10	0.07	0.18	0.10			-0.01	-0.02	-0.03	0.03	0.05	0.20	0.16	0.19	0.00	0.00
0.06	0.01	0.01	-0.04	0.02	0.20	0.20				-0.19	-0.19	-0.13	0.02	0.10	0.05	0.09	0.00	0.00
0.04	0.01	-0.09	-0.15	0.04	0.31	0.39					-0.28	-0.14	0.09	0.05	-0.04	-0.01	0.00	0.00
0.04	0.12	-0.12	-0.17	0.11	0.34	0.45						-0.09	0.16	0.04	-0.06	-0.06	0.00	0.00
	0.18	-0.11	-0.14	0.12	0.26	0.31							0.27	0.03	-0.05	-0.07	0.00	0.00
		0.01	-0.01	0.15	0.20	0.25								0.09	-0.01	-0.02	0.00	0.00
			0.05	0.10	0.09	0.07									0.00	-0.04	0.00	0.00
				0.07	0.13	0.07										-0.07	0.00	0.00
					0.03	-0.11											0.00	0.00
						-0.12												0.00
-0.03	-0.04	-0.15	-0.13	-0.07	0.22	0.09	0.00	0.05	-0.06	-0.01	-0.05	0.02	0.03	-0.15	-0.13	-0.24	0.00	0.00
-0.11	-0.09	-0.17	-0.09	0.04	0.29	0.13		0.08	-0.05	-0.02	-0.09	-0.04	-0.01	-0.17	-0.11	-0.22	0.00	0.00
-0.11	-0.14	-0.12	-0.02	0.09	0.23	0.03			0.03	0.08	-0.05	-0.03	-0.08	-0.16	-0.05	-0.13	0.00	0.00
-0.07	-0.19	-0.03	0.09	0.10	0.15	-0.06				0.12	-0.02	-0.08	-0.17	-0.15	0.04	-0.02	0.00	0.00
-0.09	-0.32	0.07	0.13	0.09	0.09	-0.09					-0.06	-0.11	-0.29	-0.08	0.11	0.08	0.00	0.00
-0.16	-0.42	0.11	0.15	0.14	0.16	0.03						-0.17	-0.34	-0.01	0.14	0.11	0.00	0.00
	-0.45	0.04	0.07	0.15	0.23	0.14							-0.38	0.03	0.16	0.12	0.00	0.00
		0.06	0.08	0.20	0.27	0.19								0.09	0.22	0.17	0.00	0.00
			0.05	0.21	0.38	0.28									0.20	0.13	0.00	0.00
				0.16	0.44	0.36										-0.05	0.00	0.00
					0.40	0.38											0.00	0.00
						0.33												0.00

S. Atlantic SSTs		Area 1 DRY DEKADS												Area 2 DRY DEKADS				
		JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ
SADI	JFM	0.01	0.08	0.03	0.08	-0.10	-0.07	-0.09	-0.08	0.07	-0.06	0.02	-0.06	-0.19	-0.14	-0.19	0.03	0.00
	FMA		0.07	0.03	0.05	-0.09	-0.04	-0.09	-0.09	0.01	-0.08	0.04	-0.03		-0.20	-0.09	0.06	0.08
	MAM			0.16	0.12	0.01	0.02	-0.08	-0.11	-0.10	-0.09	-0.01	0.02			0.06	0.07	0.15
	AMJ				0.33	0.17	0.03	-0.14	-0.14	-0.09	-0.03	-0.05	0.03				0.09	0.14
	MJJ					0.28	0.11	-0.15	-0.11	-0.07	0.05	-0.10	0.01					0.14
	JJA						0.10	-0.19	-0.14	-0.04	0.05	-0.09	-0.05					
	JAS							-0.16	-0.15	-0.06	-0.01	-0.12	-0.16					
	ASO								-0.19	-0.11	-0.12	-0.21	-0.21					
	SON									-0.14	-0.16	-0.22	-0.20					
	OND										-0.12	-0.09	0.01					
	NDJ											0.12	0.15					
	DJF												0.19					
SWAI	JFM	-0.02	-0.01	0.02	0.06	-0.04	-0.03	-0.08	-0.05	-0.05	-0.04	-0.02	0.06	-0.18	-0.16	-0.05	-0.03	0.01
	FMA		-0.07	-0.09	-0.07	-0.05	0.03	0.04	0.04	-0.07	-0.11	-0.05	0.01		-0.16	0.06	-0.02	0.09
	MAM			-0.11	-0.17	-0.02	0.06	0.17	0.10	-0.09	-0.14	-0.12	-0.01			0.18	-0.08	0.14
	AMJ				-0.03	0.09	0.04	0.15	0.09	-0.01	-0.11	-0.17	-0.06				-0.05	0.12
	MJJ					0.24	0.13	0.17	0.15	0.08	0.02	-0.16	-0.03					0.18
	JJA						0.12	0.08	0.12	0.15	0.10	-0.10	-0.03					
	JAS							0.06	0.11	0.18	0.12	-0.05	-0.07					
	ASO								0.02	0.11	-0.02	-0.21	-0.20					
	SON									-0.09	-0.12	-0.28	-0.25					
	OND										-0.19	-0.27	-0.11					
	NDJ											-0.03	0.04					
	DJF												0.08					
SCAI	JFM	-0.03	-0.10	-0.02	-0.04	0.09	0.06	0.04	0.06	-0.13	0.05	-0.04	0.12	0.09	0.04	0.19	-0.06	0.01
	FMA		-0.15	-0.11	-0.12	0.07	0.07	0.15	0.14	-0.07	0.01	-0.08	0.05		0.13	0.17	-0.08	-0.02
	MAM			-0.30	-0.29	-0.03	0.03	0.25	0.23	0.05	-0.01	-0.08	-0.03			0.08	-0.16	-0.07
	AMJ				-0.46	-0.13	0.00	0.33	0.27	0.10	-0.07	-0.09	-0.10				-0.17	-0.07
	MJJ					-0.15	-0.02	0.35	0.28	0.16	-0.04	-0.02	-0.04					-0.01
	JJA						-0.03	0.33	0.30	0.20	0.02	0.02	0.04					
	JAS							0.28	0.30	0.24	0.13	0.13	0.15					
	ASO								0.28	0.25	0.16	0.14	0.13					
	SON									0.13	0.14	0.10	0.09					
	OND										0.02	-0.07	-0.08					
	NDJ											-0.16	-0.14					
	DJF												-0.17					

Area 2 DRY DEKADS							Area 3 DRY DEKADS											
JJA	JAS	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ	DJF
0.19	0.10	0.06	0.12	-0.03	0.00	-0.14	-0.23	-0.20	-0.43	-0.30	-0.30	-0.04	0.03	-0.03	0.04	-0.02	0.12	-0.03
0.15	0.03	-0.09	-0.01	-0.05	0.00	-0.20		-0.25	-0.34	-0.30	-0.26	-0.10	0.02	-0.11	-0.11	-0.16	0.02	-0.15
0.11	0.00	-0.23	-0.16	-0.15	-0.12	-0.27			-0.09	-0.19	-0.13	-0.08	0.02	-0.20	-0.29	-0.31	-0.17	-0.21
0.00	-0.09	-0.29	-0.20	-0.17	-0.22	-0.27				-0.04	-0.02	-0.15	-0.12	-0.33	-0.37	-0.32	-0.30	-0.19
0.00	-0.14	-0.26	-0.13	-0.06	-0.20	-0.16					0.04	-0.10	-0.22	-0.34	-0.35	-0.16	-0.32	-0.10
-0.08	-0.25	-0.25	-0.05	0.06	-0.08	-0.08						-0.13	-0.35	-0.37	-0.26	0.03	-0.18	-0.03
	-0.29	-0.23	0.03	0.18	0.05	-0.02							-0.32	-0.32	-0.17	0.14	-0.08	-0.01
		-0.26	-0.05	0.08	-0.03	-0.08								-0.31	-0.18	0.08	-0.11	-0.05
			0.01	0.09	-0.04	-0.04									-0.09	0.05	-0.10	0.01
				0.06	-0.04	0.03										0.01	-0.05	0.15
					0.07	0.07											0.14	0.25
						-0.03												0.16
0.08	0.08	0.21	0.04	-0.06	-0.32	-0.32	-0.15	-0.18	-0.19	-0.22	-0.15	-0.08	0.01	-0.01	-0.08	-0.20	-0.18	-0.20
0.07	0.14	0.12	-0.02	-0.11	-0.25	-0.33		-0.26	-0.13	-0.27	-0.11	-0.14	0.10	-0.01	-0.09	-0.28	-0.20	-0.28
0.01	0.23	0.05	-0.08	-0.20	-0.25	-0.29			0.04	-0.24	0.02	-0.12	0.23	0.01	-0.09	-0.36	-0.30	-0.31
-0.07	0.23	0.04	-0.03	-0.20	-0.25	-0.21				-0.15	0.09	-0.16	0.17	-0.05	-0.07	-0.33	-0.34	-0.28
0.01	0.24	0.09	0.09	-0.07	-0.18	-0.01					0.18	-0.04	0.12	-0.03	-0.02	-0.18	-0.37	-0.19
-0.04	0.09	0.07	0.21	0.07	-0.04	0.09						-0.04	-0.05	-0.08	0.06	0.00	-0.23	-0.09
	0.02	0.07	0.31	0.25	0.16	0.17							-0.07	-0.05	0.14	0.11	-0.12	-0.07
		-0.03	0.20	0.11	0.03	0.02								-0.09	0.09	-0.01	-0.25	-0.21
			0.13	0.10	-0.02	0.00									0.01	-0.04	-0.27	-0.17
				-0.01	-0.16	-0.03										-0.08	-0.28	-0.05
					-0.04	0.01											-0.03	0.15
						-0.07												0.07
-0.16	-0.06	0.09	-0.12	-0.01	-0.25	-0.07	0.17	0.10	0.38	0.19	0.25	-0.01	-0.02	0.02	-0.11	-0.13	-0.29	-0.12
-0.14	0.07	0.21	-0.01	-0.02	-0.20	-0.01		0.11	0.32	0.16	0.24	0.02	0.06	0.13	0.06	-0.03	-0.19	-0.04
-0.13	0.20	0.33	0.13	0.01	-0.07	0.09			0.14	0.03	0.18	-0.01	0.17	0.26	0.29	0.07	-0.04	-0.01
-0.06	0.34	0.41	0.23	0.02	0.05	0.14				-0.09	0.12	0.04	0.32	0.38	0.42	0.09	0.06	-0.02
0.01	0.40	0.42	0.25	0.01	0.09	0.19					0.12	0.09	0.40	0.41	0.43	0.03	0.07	-0.05
0.07	0.43	0.41	0.25	-0.02	0.07	0.19						0.14	0.43	0.43	0.41	-0.04	0.03	-0.05
	0.41	0.37	0.24	-0.03	0.07	0.18							0.37	0.38	0.36	-0.09	0.00	-0.04
		0.34	0.24	-0.01	0.09	0.14								0.35	0.34	-0.12	-0.04	-0.11
			0.10	-0.04	0.05	0.07									0.15	-0.11	-0.09	-0.17
				-0.09	-0.07	-0.06										-0.09	-0.16	-0.25
					-0.13	-0.08											-0.20	-0.20
						-0.02												-0.15